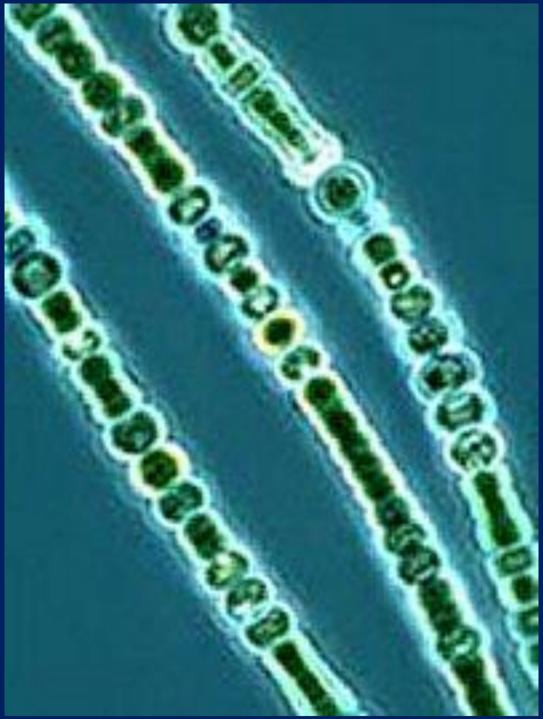
Хемолитотрофия и фототрофия



с/к «Биохимия клетки»
Лекция 2-1

	ХЕМОТРОФИЯ									
	Хемоорганотрофы					**Хемолитотрофы**				
Источник С	Органические соед-я					CO_2				
Донор электронов	Органические соед-я					H_2S / S	NH_3	NO_2	H_2	
Акцептор электронов	Органич. соединения	NO_3-	NO_2-	SO_4^{2-}	O_2	O_2				CO_2
Обмен	Анаэробный				Аэробный					Анаэроб
Ассимиляция энергии	в виде химич. потенциала субстрата	в виде трансмембранного электрохимического потенциала								
Локализация	Цитозольные реакции (ДГ)	Мембранные системы ЭТЦ (цитохромы, Fe-S-центры, хиноны)								
Синтез АТФ	субстратное фосфорил-е; превращение тиоэфиров	Окислительное фосфорилирование								
	Брожение	**Дыхание (анаэробное и аэробное)**								

Основные группы хемолитотрофов

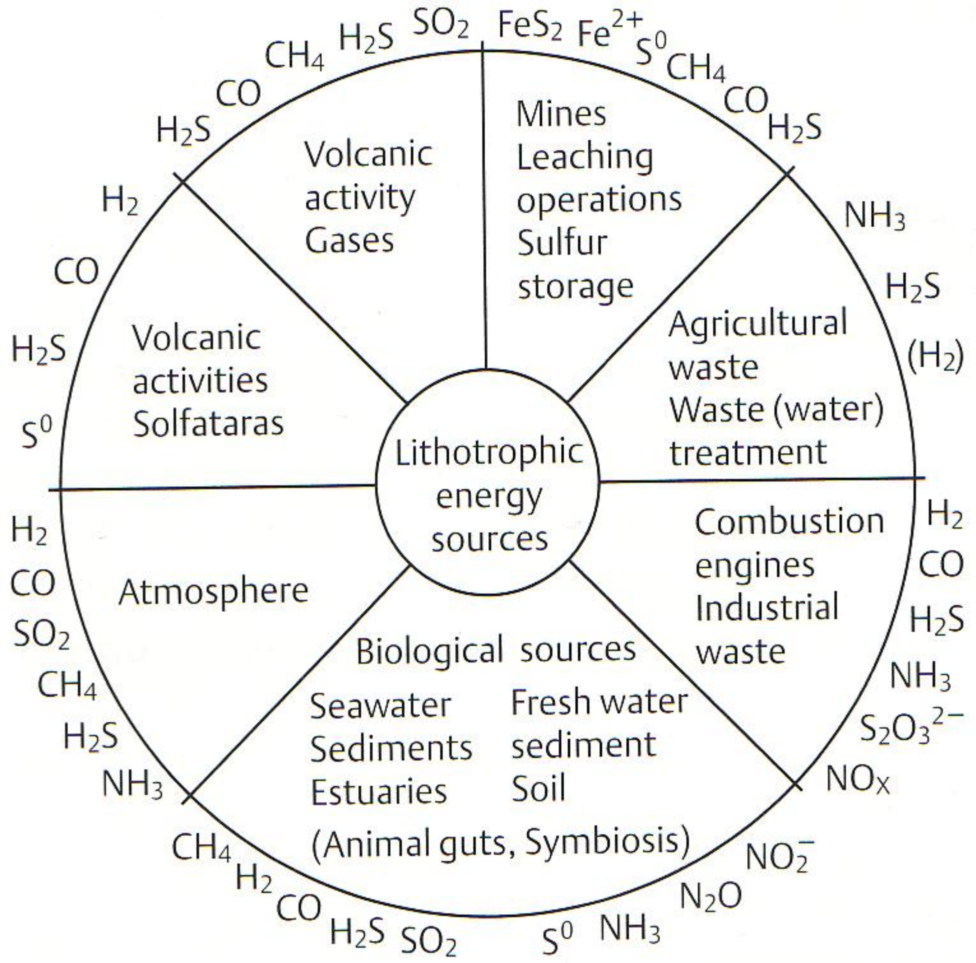
Группа	Реакции, ведущие к синтезу АТФ	Донор е	Продукт окисления
Водородные бактерии	$H_2+ 1/2O_2 \rightarrow H_2O$	Водород	Вода
Серо-бактерии, окисляющие а) сульфиды, б) элементарную серу	$S_2^{-}+2O_2 \rightarrow SO_4^{2-}$ $S^{\circ}+1/2O_2+H_2O \rightarrow SO_4^{2-}+2H^{+}$	Сульфиды, элемент. сера, тиосульфаты	Сульфаты
Бактерии, окисляющие аммиак	$NH_4^{+}+1{,}5O_2 \rightarrow NO_2+2H^{+}+H_2O$	Аммиак	Диоксид азота
Бактерии, окисляющие нитриты	$NO_2{-}+1/2O_2 \rightarrow NO_3^{-}$	Нитриты	Нитраты
Железо-бактерии	$Fe^{2+}+1/4O_2+H^{+} \rightarrow Fe^{3+}+1/2H_2O$	Восст.железо	Окисл.железо

Во всех вариантах акцептор электронов - кислород

К другим типам хемолитотрофии относят:

- 1) окисление других металлов, кроме железа (марганца, меди, олова и др.)
- 2) углеродную хемолитотрофию (окисление метана, формиата, монооксида углерода, метильных групп) – бактерии (метано-, метило- и карбоксидотрофы, формиатокисляющие) и археи (метилотрофы и метаногены)

Geological, biological, and anthropogenic sources of reduced inorganic compounds supporting chemolithotrophs


Lithotrophic energy sources
Volcanic activity Gases
H_2 H_2S CO CH_4 H_2S SO_2
Mines Leaching operations Sulfur storage
FeS_2 Fe^{2+} S^0 CH_4 CO H_2S
Agricultural waste Waste (water) treatment
NH_3 H_2S (H_2)
Combustion engines Industrial waste
H_2 CO H_2S NH_3 $S_2O_3^{2-}$ NO_x
Biological sources
Seawater Sediments Estuaries
Fresh water sediment Soil
(Animal guts, Symbiosis)
NO_2^- N_2O NH_3 S^0 SO_2 H_2S CO H_2 CH_4
Atmosphere
H_2 CO SO_2 CH_4 H_2S NH_3
Volcanic activities Solfataras
CO H_2S S^0

Typical habitats of chemolithotrohs:

Near the interface of oxic/anoxic conditions

Гидрогеназа и дыхательная цепь водород-окисляющих бактерий

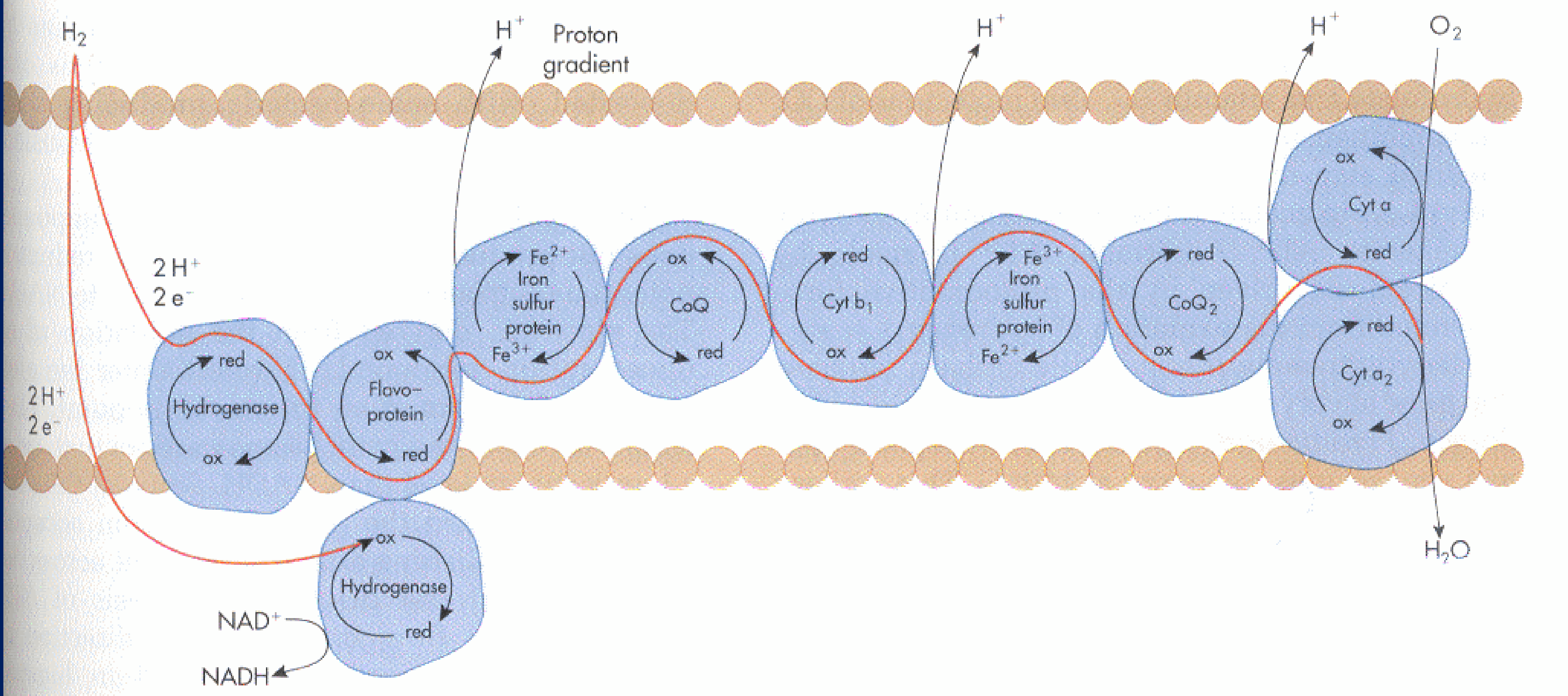
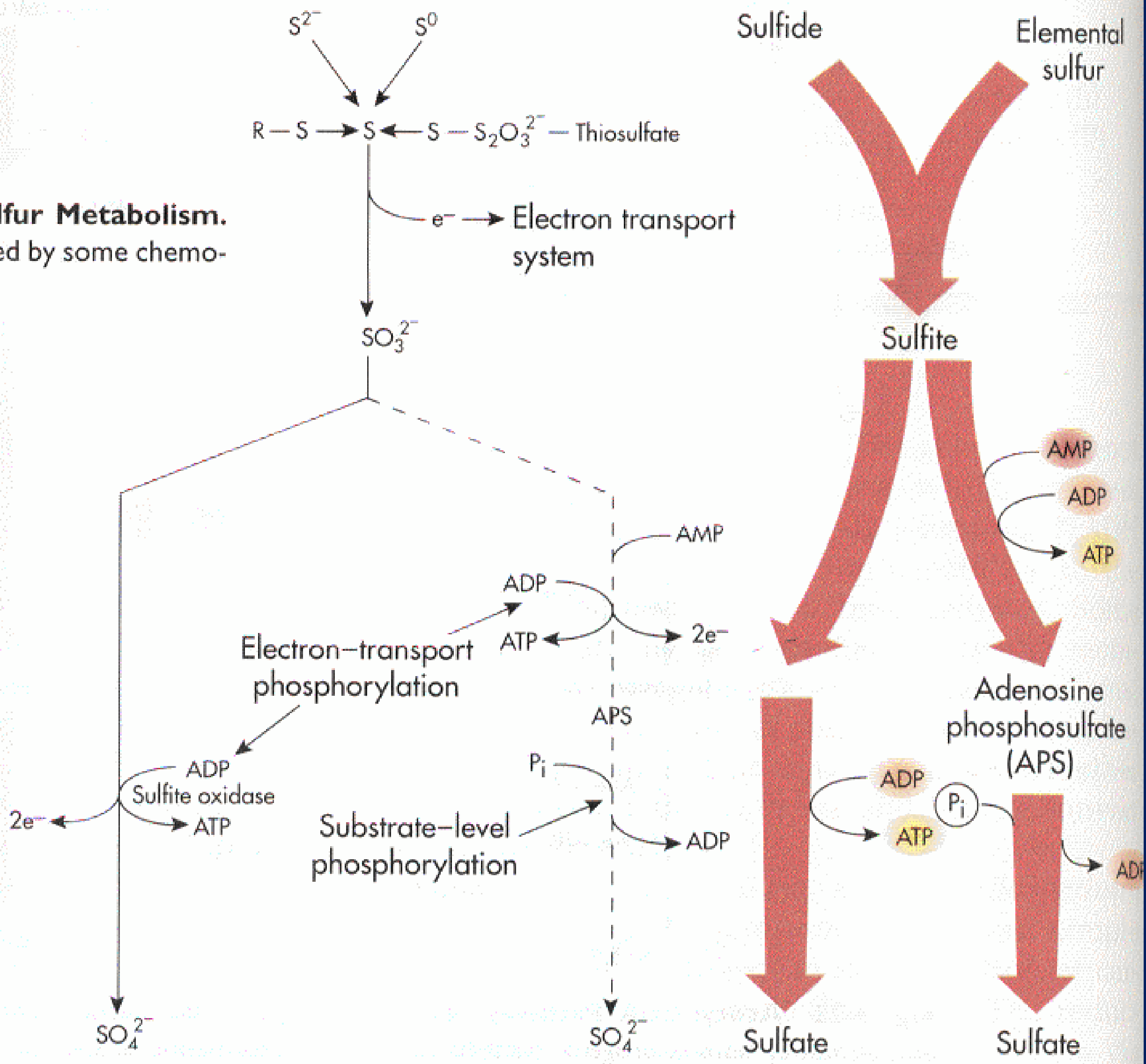


Fig. 4-21 Hydrogenase and Chemolithotrophic Metabolism. Hydrogenase splits hydrogen into protons and electrons that are transported via a membrane-bound electron transport system. This transport establishes a proton gradient.

Серная хемолитотрофия



S^{2-}
S^0
$R-S \rightarrow S \leftarrow S - S_2O_3^{2-}$ — Thiosulfate
$e^- \rightarrow$ Electron transport system
SO_3^{2-}
AMP
ADP
ATP
2e⁻
APS
Electron–transport phosphorylation
ADP
Sulfite oxidase
2e⁻
ATP
P_i
Substrate–level phosphorylation
ADP
SO_4^{2-}
SO_4^{2-}
Sulfide
Elemental sulfur
Sulfite
AMP
ADP
ATP
Adenosine phosphosulfate (APS)
ADP
ATP
P_i
AD
Sulfate
Sulfate

Fig. 4-23 Chemolithotrophic Sulfur Metabolism. Sulfides and elemental sulfur are oxidized by some chemolithotrophs to sulfate.

Азотная хемолитотрофия

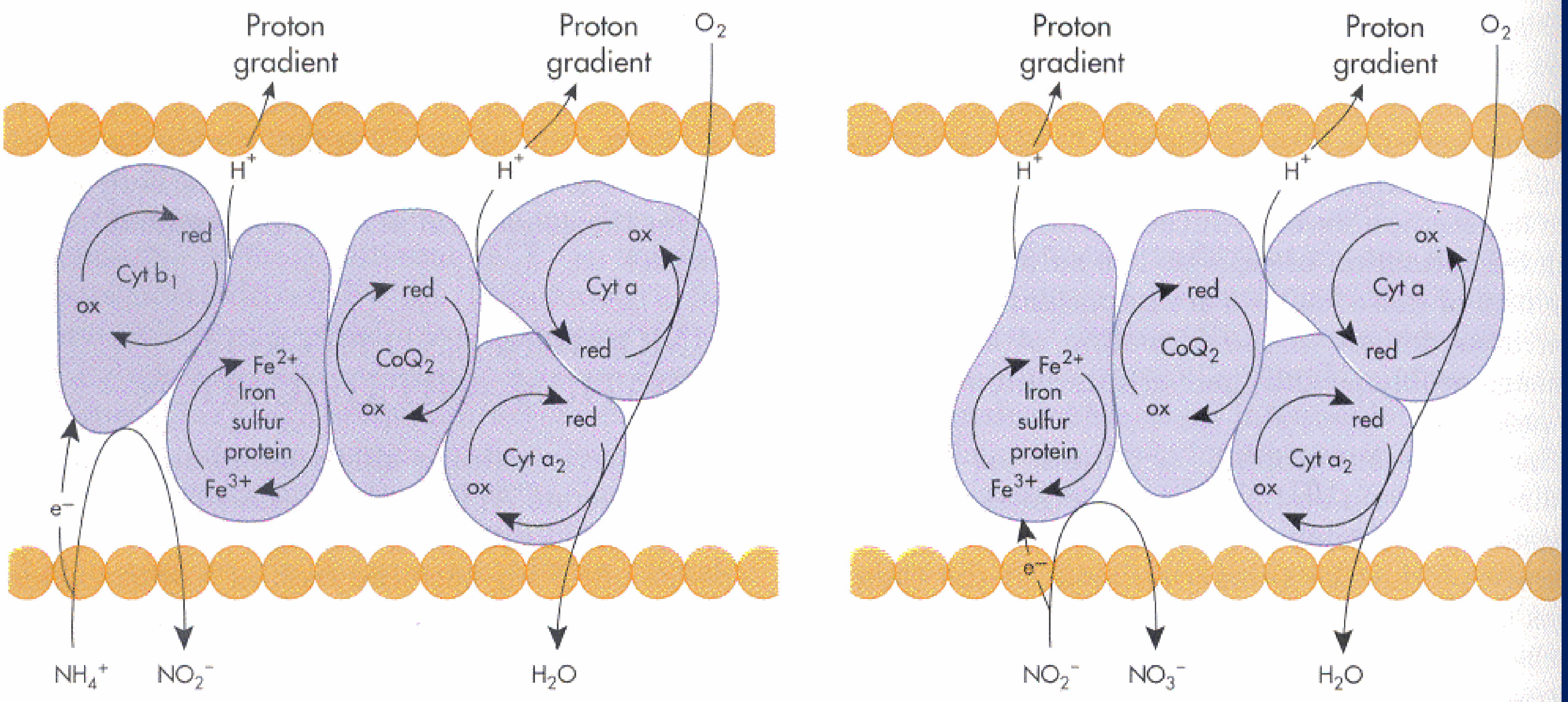


Fig. 4-24 Chemolithotrophic Nitrogen Metabolism—Nitrifying Bacteria. Nitrifying bacteria are chemolithotrophs that oxidize inorganic nitrogen compounds to generate ATP. Some, such as *Nitrosomonas*, oxidize ammonium ions (NH_4^+) to nitrite ions (NO_2^-) *(left)*; others, such as *Nitrobacter*, oxidize nitrite ions to nitrate ions (NO_3^-) *(right)*.

	ФОТОтрофия			
	Фотоорганотрофы		**Фотолитотрофы**	
Источник С	Орг.соед-я		CO_2	
Донор электронов для восст.коф-тов	Орг.соед-я		H_2S S	H_2O
Акцептор электронов	Бактерио-родопсин	NAD+		NADP+
Обмен	Анаэробный			Аэробный
Локализация	Мембранные системы ЭТЦ (хлорофилл-содержащие ФС, цитохромы, Fe-S-центры, хиноны)			
Ассимиляция энергии	в виде трансмембранного электрохимического потенциала			
Синтез АТФ	Фототрансдукция	Аноксигенный фотосинтез по цикл.схеме		Оксигенный ФС по Z-схеме
	→ окислительное фотофосфорилирование			

Anoxygenic photosynthesis found in:

- Purple sulfur bacteria (e.g. *Chromatium*)
- Purple nonsulfur bacteria (e.g. *Rhodobacter*)
- Green sulfur bacteria (e.g. *Chlorobium*)
- Green nonsulfur bacteria (e.g. *Chloroflexus*)

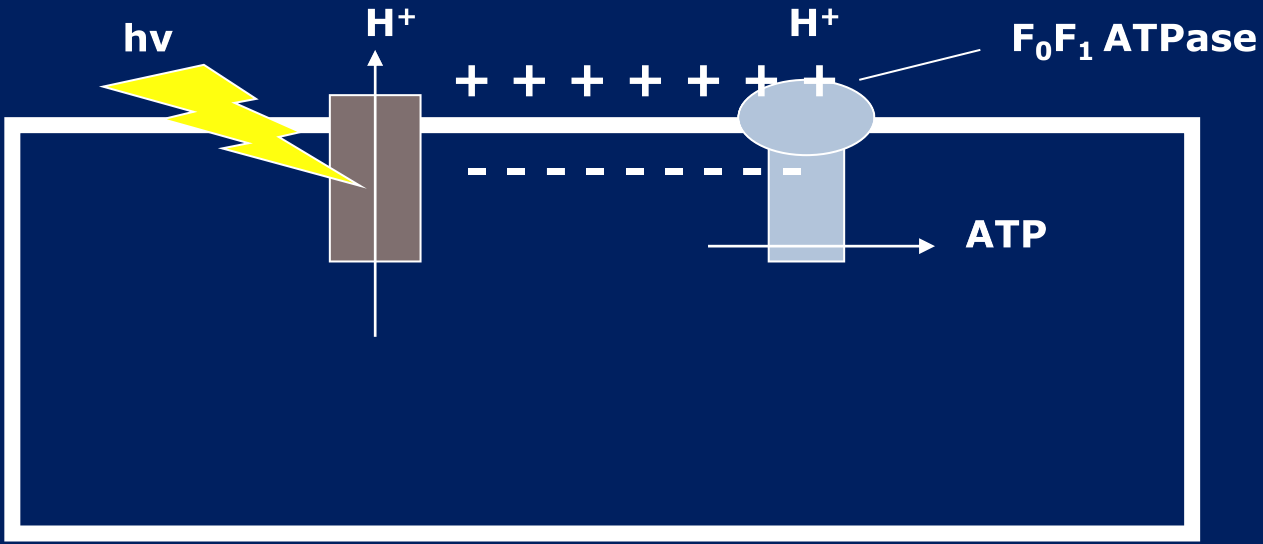
	ФОТОтрофия			
	Фотоорганотрофы		ФотоЛИТОтрофы	
Источник С	Орг.соед-я		CO_2	
Донор электронов для восст.коф-тов	Орг.соед-я		H_2S S	H_2O
Акцептор электронов	Бактерио-родопсин	NAD+		NADP+
Обмен	Анаэробный			Аэробный
Локализация	Мембранные системы ЭТЦ (хлорофилл-содержащие ФС, цитохромы, Fe-S-центры, хиноны)			
Ассимиляция энергии	в виде трансмембранного электрохимического потенциала			
Синтез АТФ	Фототрансдукция	Аноксигенный фотосинтез по цикл.схеме		Оксигенный ФС по Z-схеме
	→ окислительное фотофосфорилирование			

Anoxygenic photosynthesis found in:

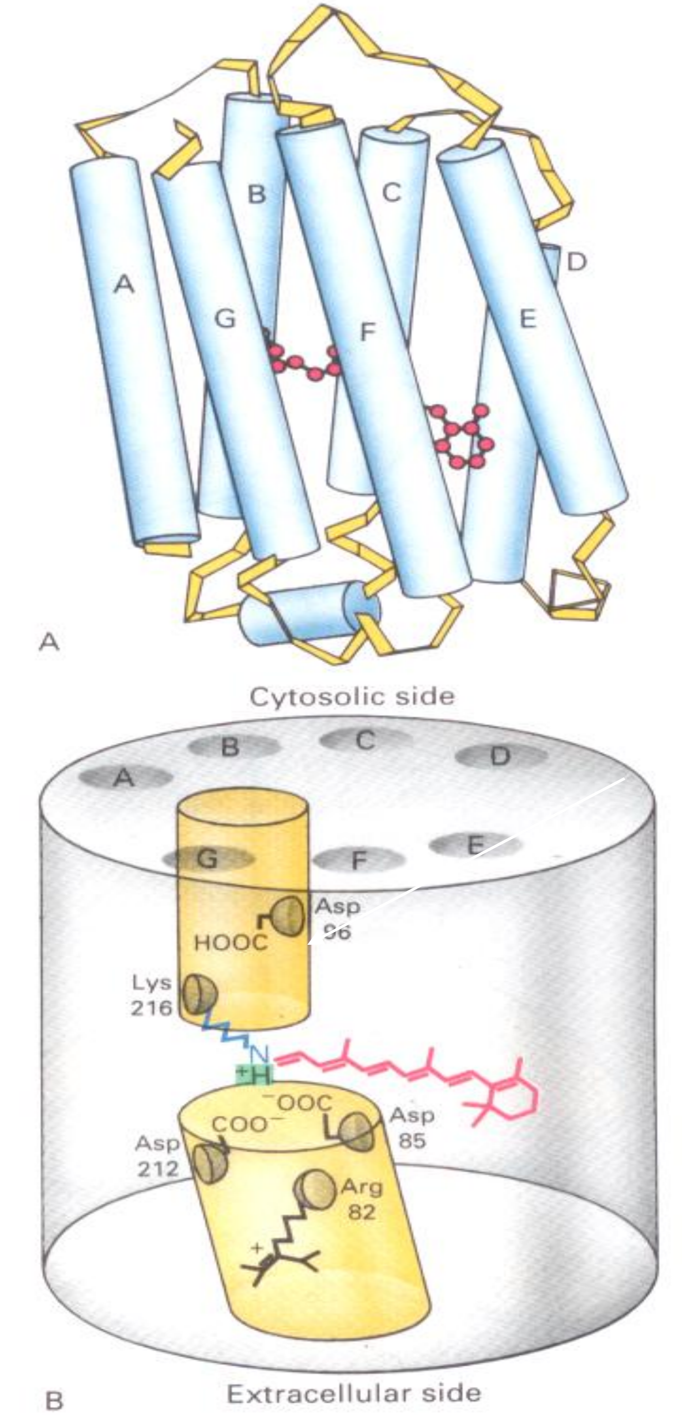
- Purple sulfur bacteria (e.g. *Chromatium*)
- Purple nonsulfur bacteria (e.g. *Rhodobacter*)
- Green sulfur bacteria (e.g. *Chlorobium*)
- Green nonsulfur bacteria (e.g. *Chloroflexus*)

Halobacterium halobium

- **Resides in hypertonic environments (shallow waters of San Francisco bay)**
- **Diatomic oxygen is plentiful = OXPHOS**
- **Diatomic oxygen unavailable = LIGHT HARVESTING**
  - **Achieved by Bacteriorhodopsin, a 26 KD protein with all-trans-retinal attached**
- **LIGHT IS CONVERTED DIRECTLY INTO A H^+ MOTIVE FORCE**

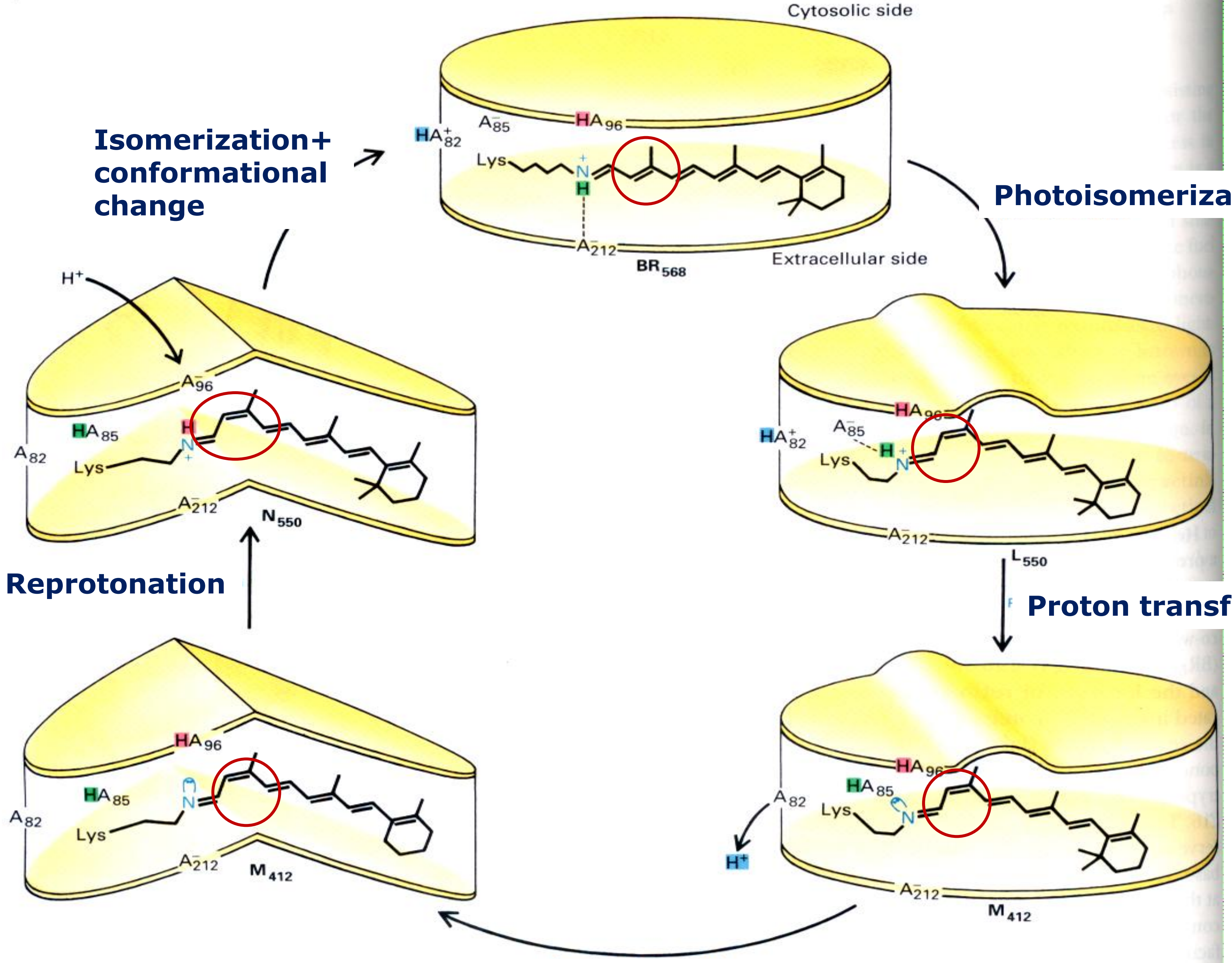


Bacteriorhodopsin



Several transmem spanning helices
3 Tyr hold the BR in place

Retinal sits at the junction separating the two "half" channels



Isomerization+ conformational change

Photoisomerization

Proton transfer

Reprotonation

Change of conformation

	ФОТОтрофия			
	Фотоорганотрофы		**ФотоЛИТОтрофы**	
Источник С	Орг.соед-я		CO_2	
Донор электронов для восст.коф-тов	Орг.соед-я		H_2S S	H_2O
Акцептор электронов	Бактерио-родопсин	NAD+		NADP+
Обмен	Анаэробный			Аэробный
Локализация	Мембранные системы ЭТЦ (хлорофилл-содержащие ФС, цитохромы, Fe-S-центры, хиноны)			
Ассимиляция энергии	в виде трансмембранного электрохимического потенциала			
Синтез АТФ	Фототрансдукция	Аноксигенный фотосинтез по цикл.схеме		Оксигенный ФС по Z-схеме
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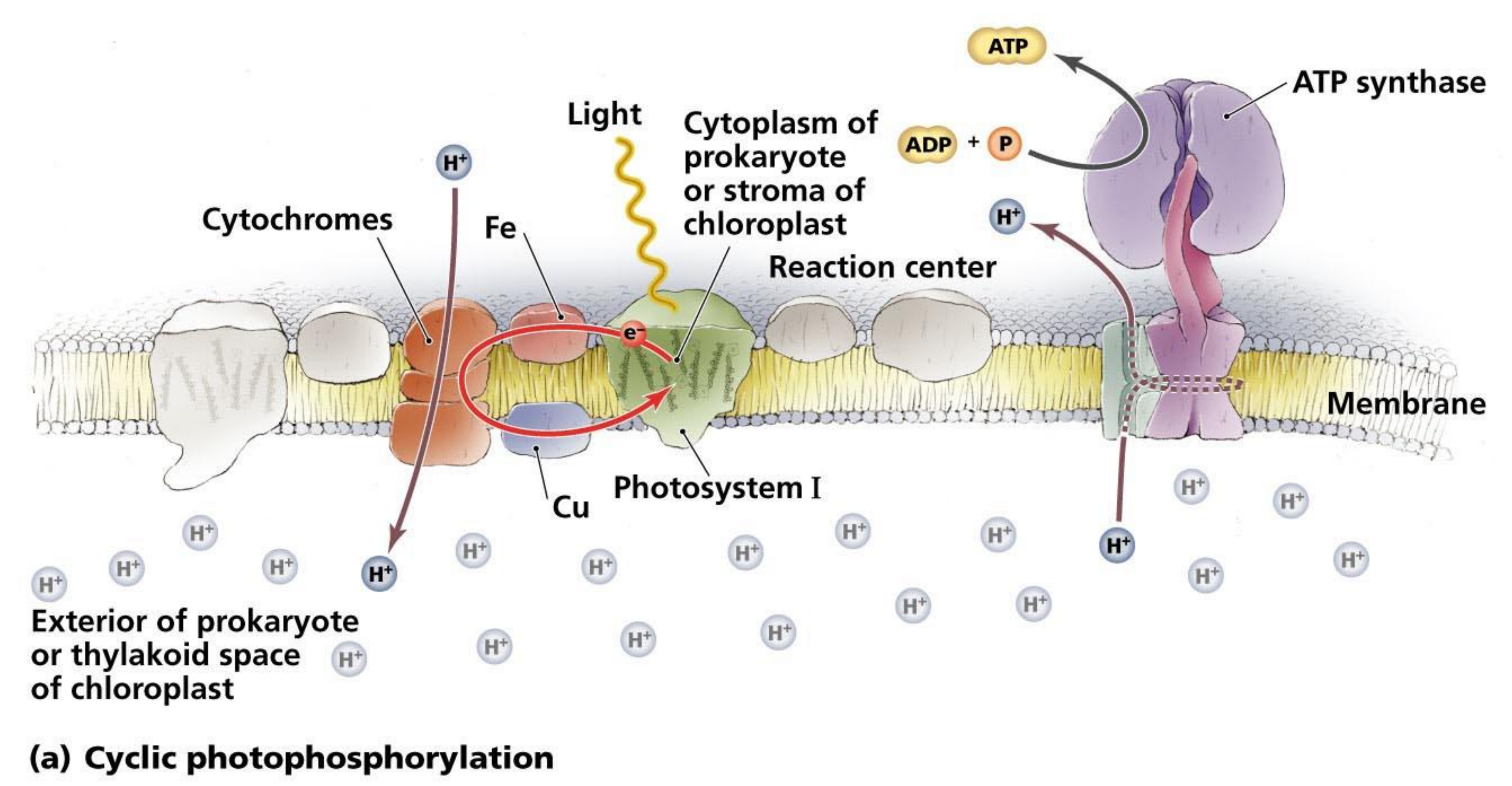
- Green sulfur bacteria (e.g. *Chlorobium*)
- Green nonsulfur bacteria (e.g. *Chloroflexus*)

Cyclic Photophosphorylation


ATP
ATP synthase
Light
Cytoplasm of prokaryote or stroma of chloroplast
ADP
+
P
H^+
Cytochromes
Fe
Reaction center
e⁻
Membrane
Cu
Photosystem I
Exterior of prokaryote or thylakoid space of chloroplast

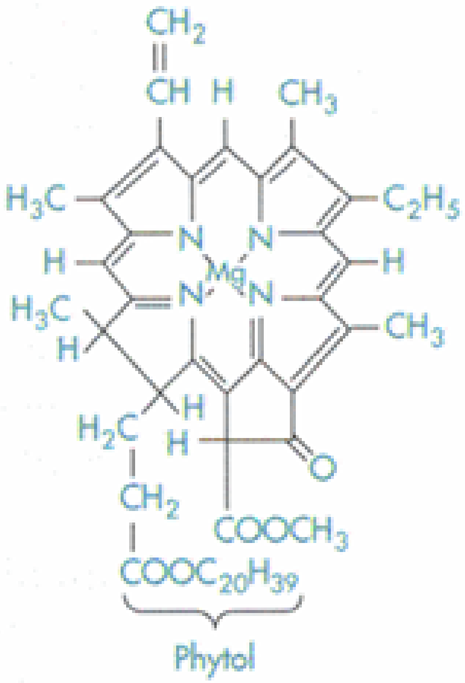
(a) Cyclic photophosphorylation

Figure 5.28a

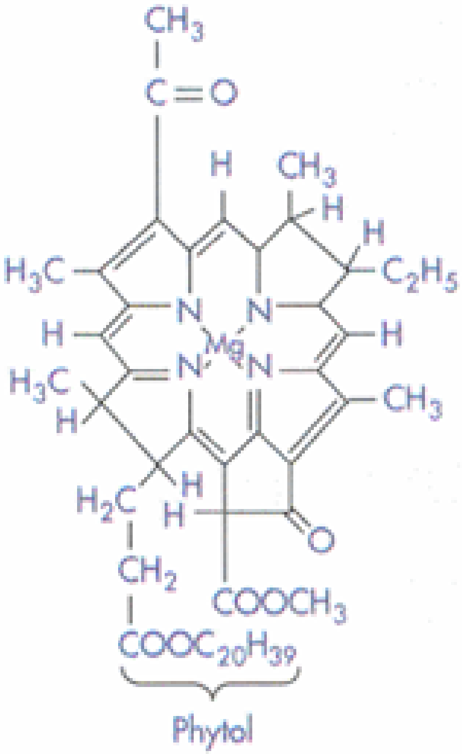
Properties of microbial photosynthetic systems

	Cyanobacteria	**Purple sulfur and Green bacteria**	**Purple nonsulfur bacteria**
Photopigment	Chlorophyll	Bacteriochlorophyll	
O_2 production	Yes	**No**	No
Electron donors	H_2O	H_2, H_2S, S	
Carbon source	CO_2	CO_2	**Organic** / CO_2
Primary products of energy conversion	ATP + NADPH	ATP	ATP

Особенности строения бактериальных фотосинтетических пигментов

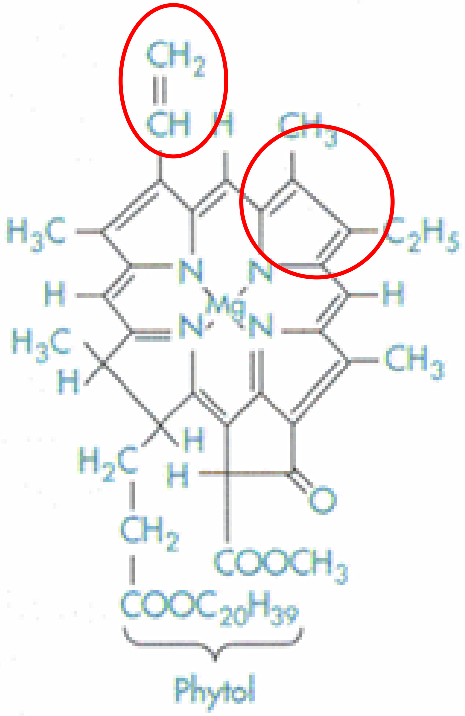


Chlorophyll *a*

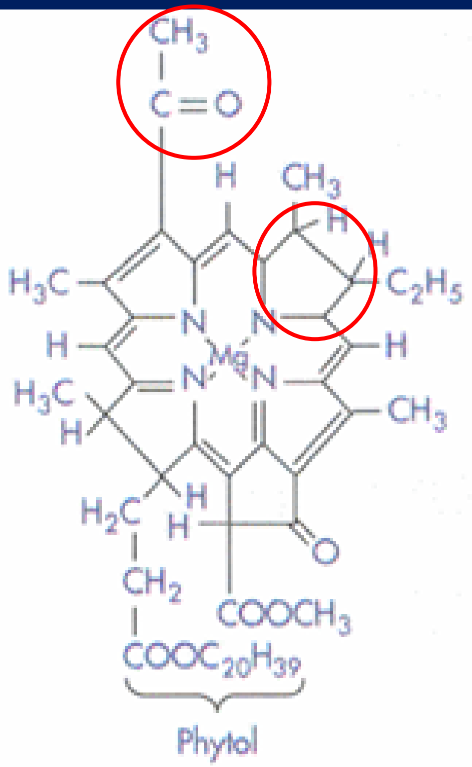


Bacteriochlorophyll *a*

Особенности строения бактериальных фотосинтетических пигментов

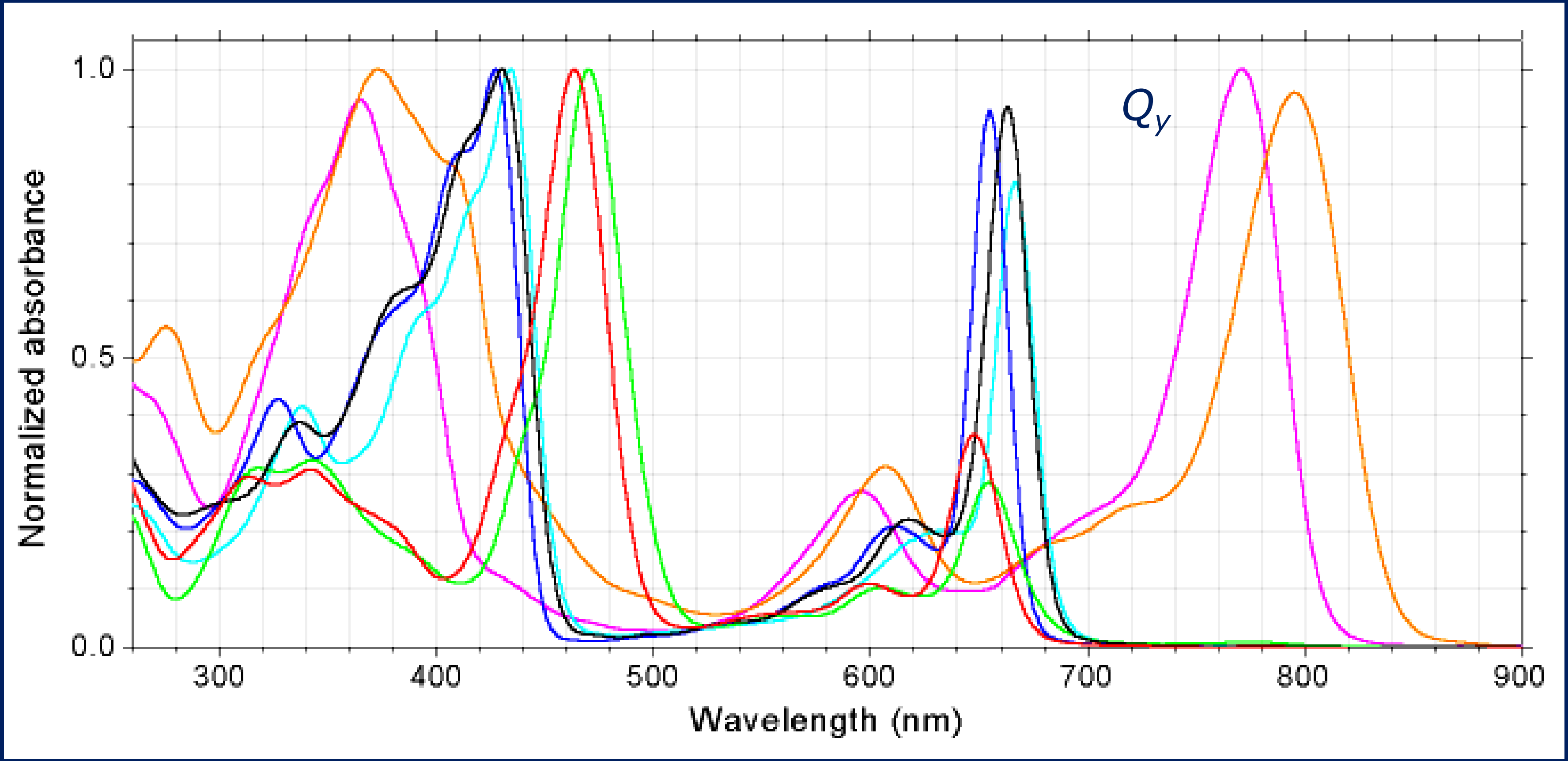


Chlorophyll *a*



Bacteriochlorophyll *a*

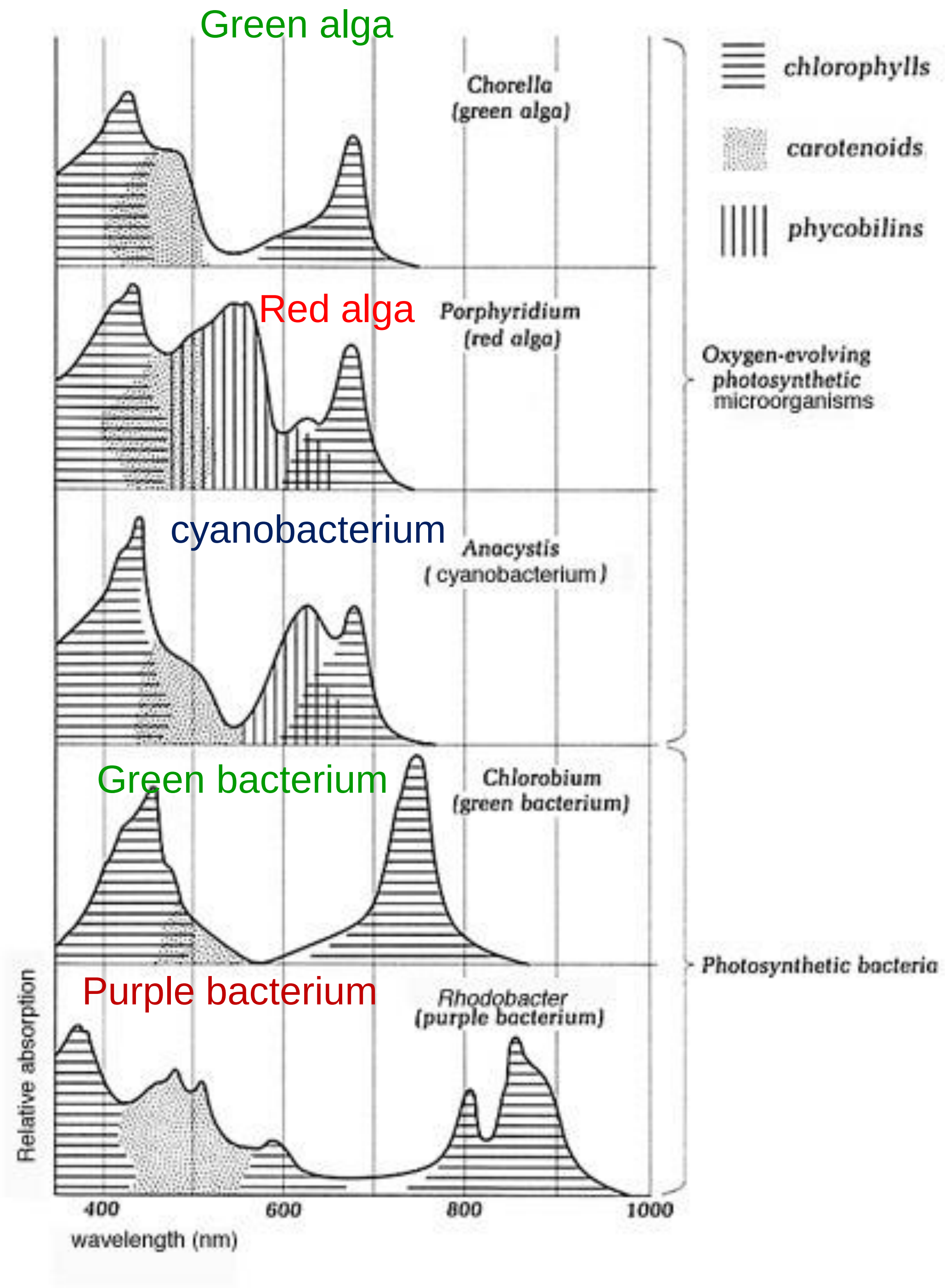
Absorption spectra of various chlorophylls in methanol

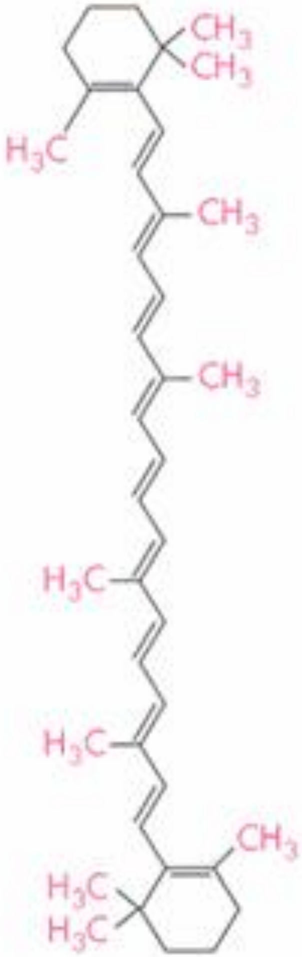


Chl*a*: black
Chl*b*: red
BChl*a*: magenta
BChl*b*: orange
BChl*c*: cyan
BChl*d*: blue
BChl*e*: green

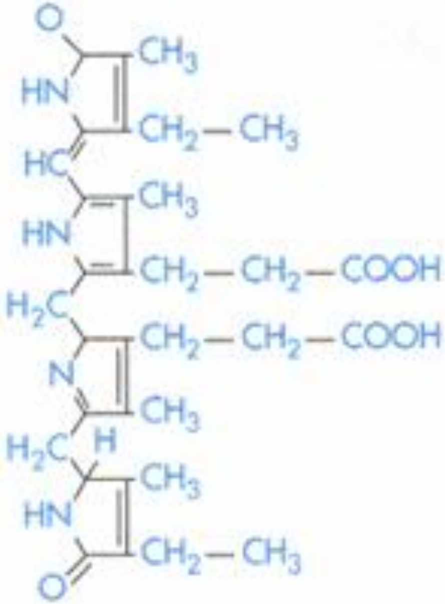
Source: Frigaard *et al. (1996), FEMS Microbiol. Ecol. 20: 69-77*

The distribution of photosynthetic pigments among photosynthetic microorganisms.



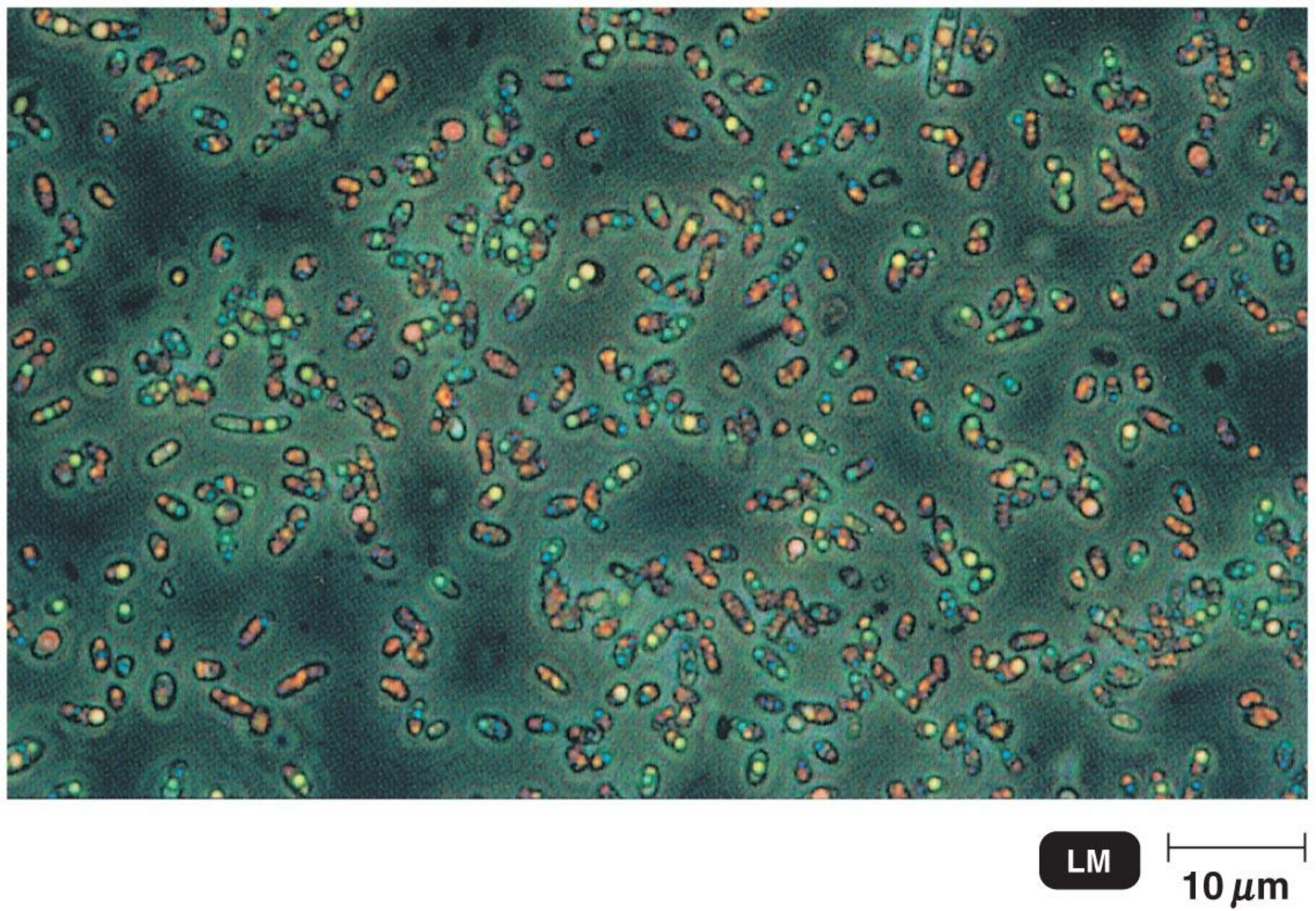


α−carotene

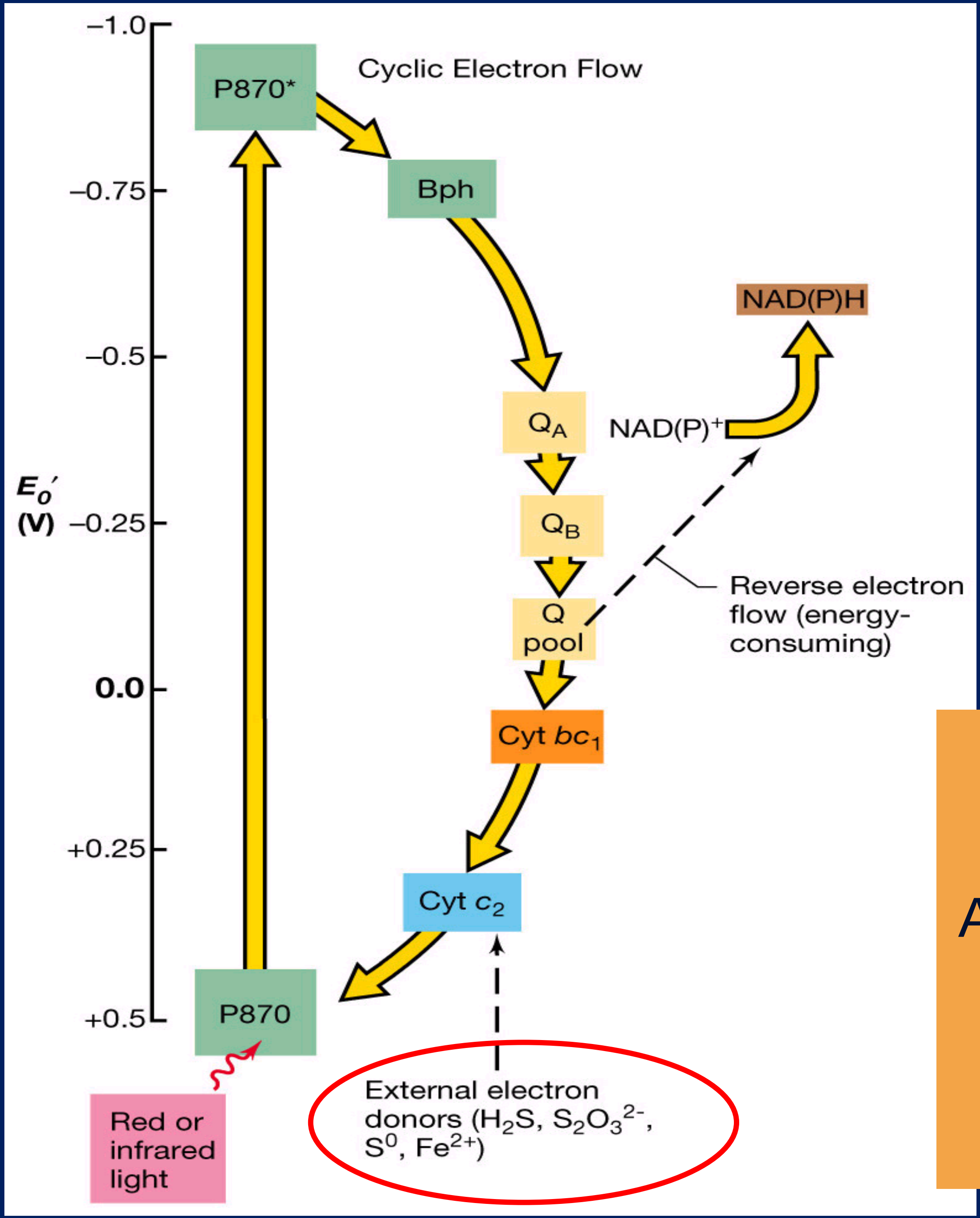


Phycocyanin

Purple Sulfur Bacteria

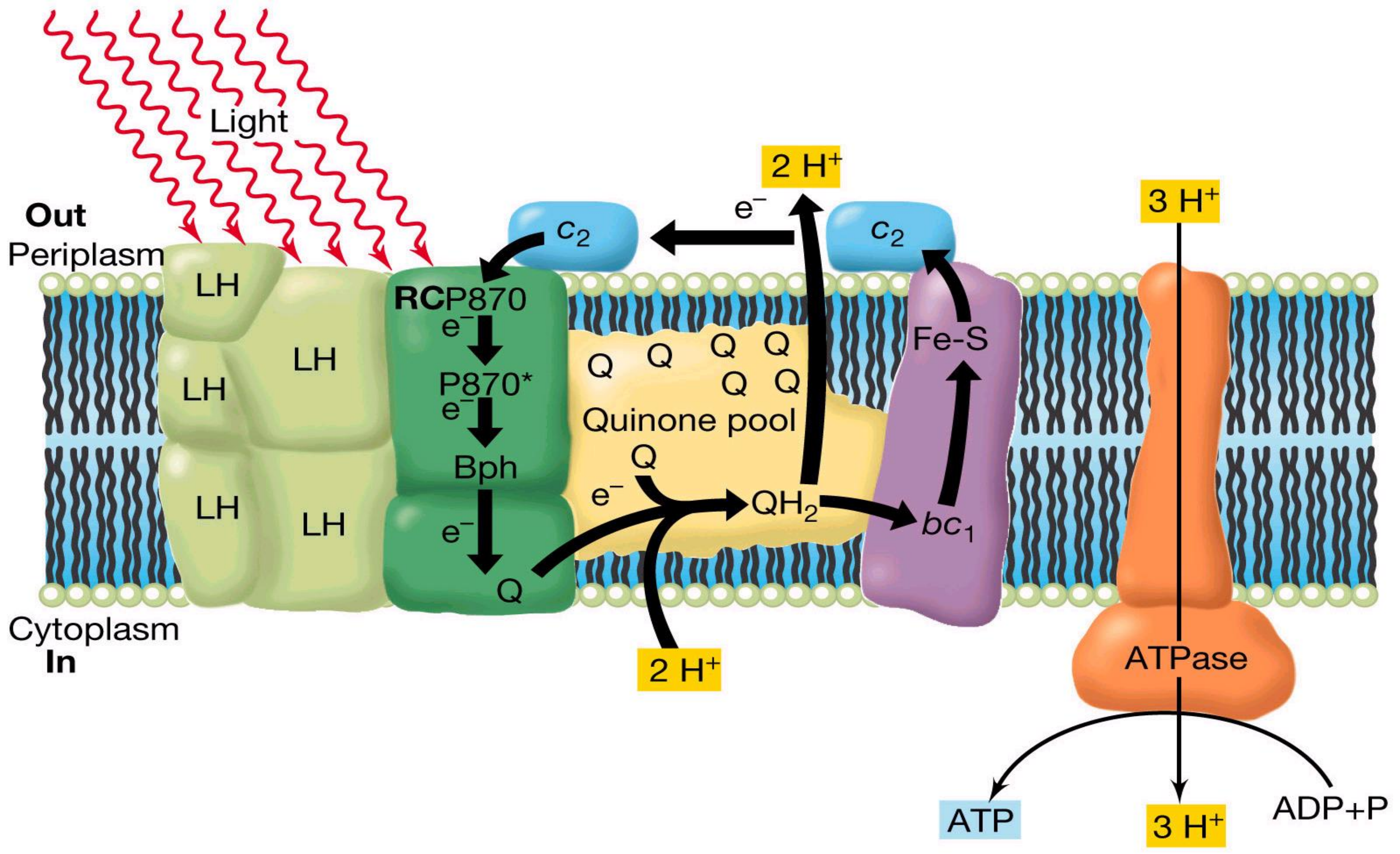


Циклическая схема бактериального фотосинтеза

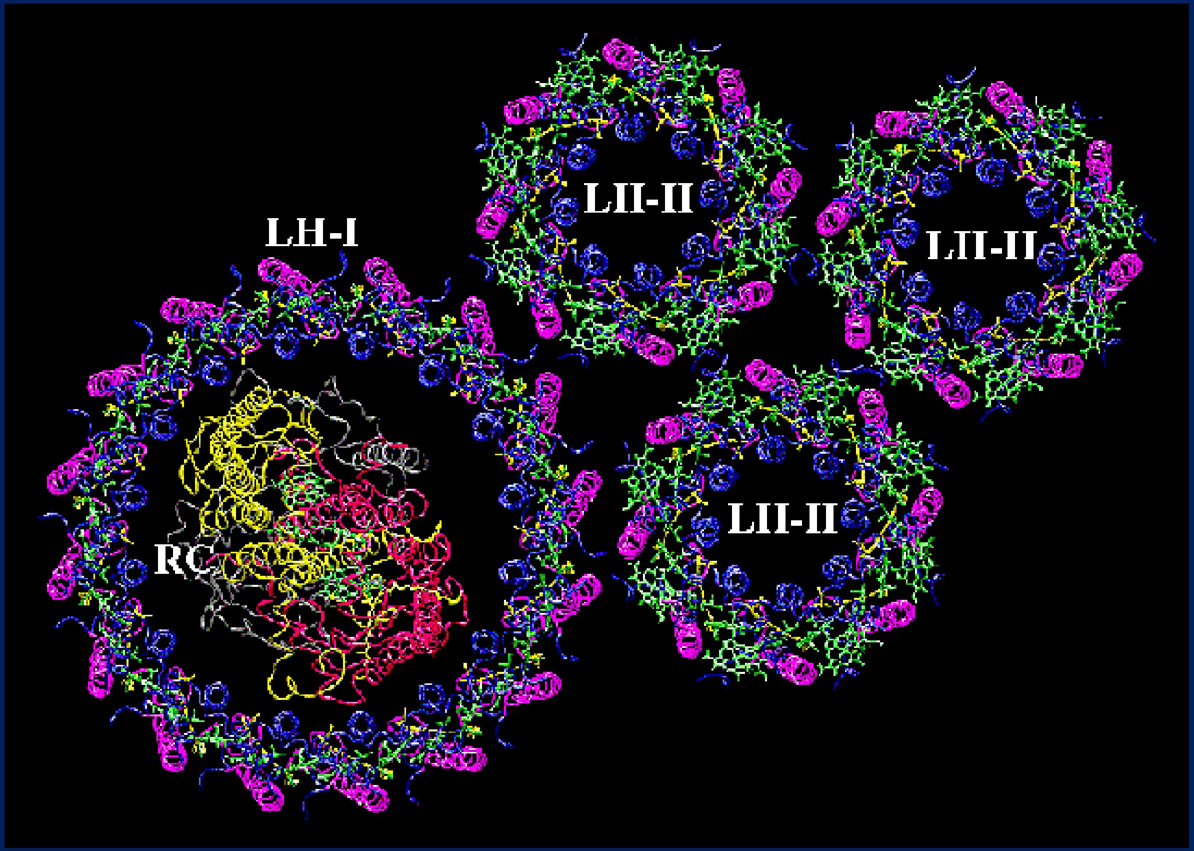


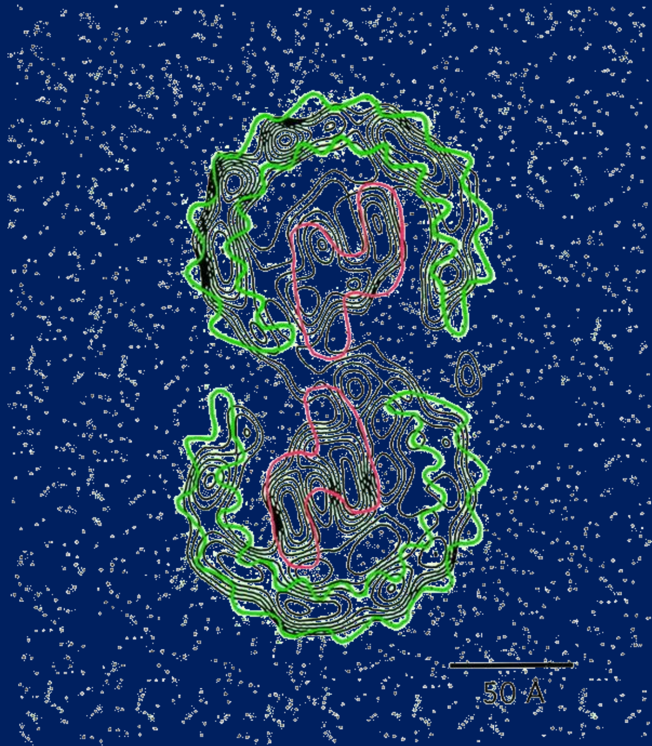
Autotrophy in Purple Anoxygenic Phototrophs (e^- donors and reverse e^- flow)

Purple Anoxygenic Phototrophic Photosynthetic Membrane



Antenna and RC complexes (model)



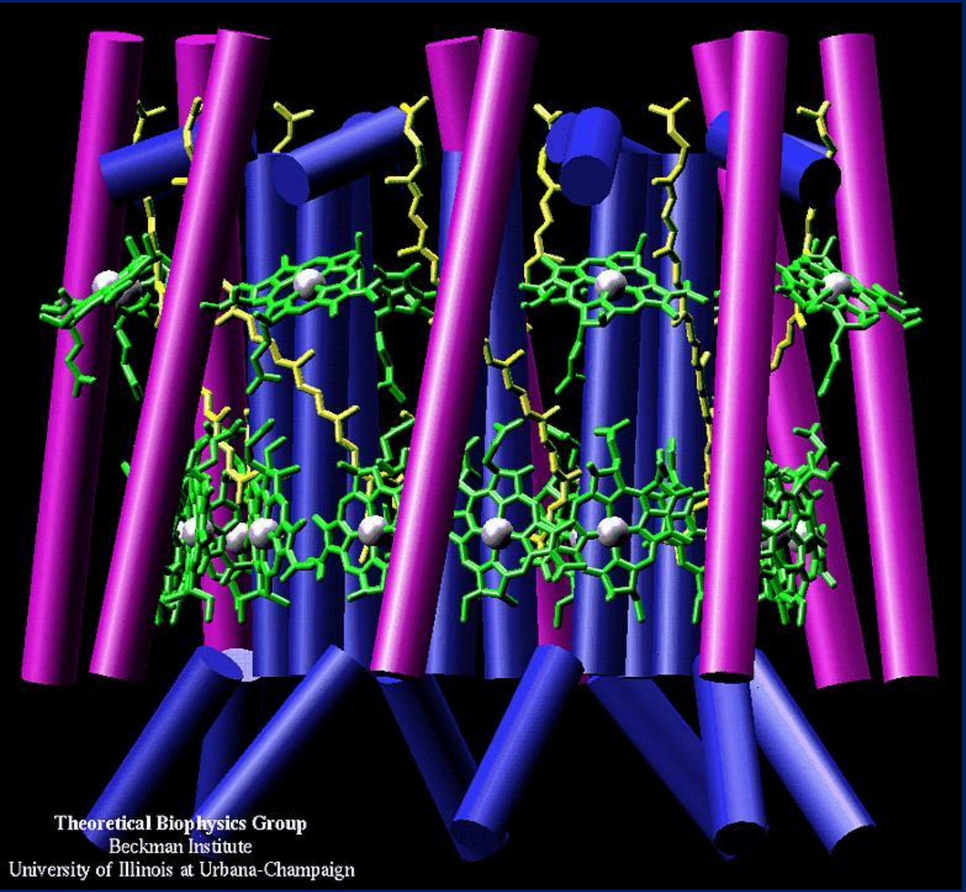


This allows the UQ to leave the RC. Likely the PufX protein plays a role here.

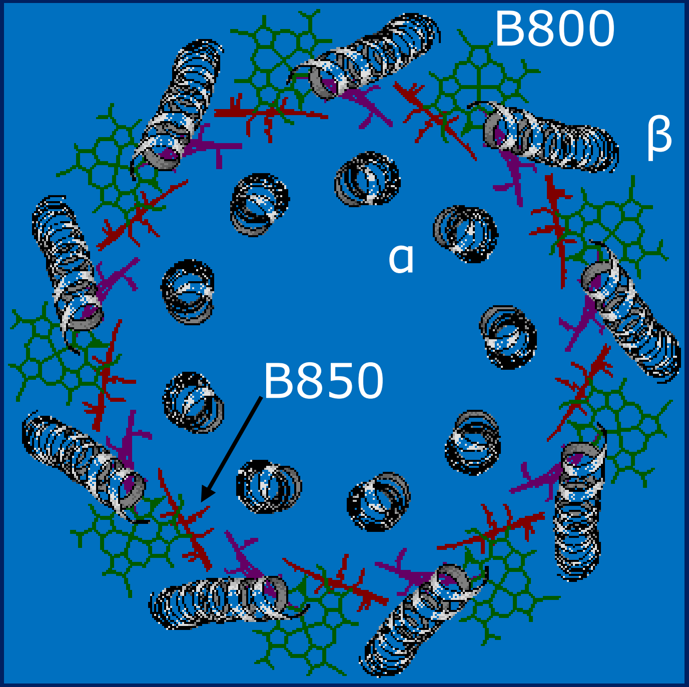
NB: atomic resolution structural models for LH1 are based on LH2 structure

LH2 structure and pigments

Richard J. Cogdell’s webpages:
www.gla.ac.uk/ibls/BMB/rjc/lh2galery.htm

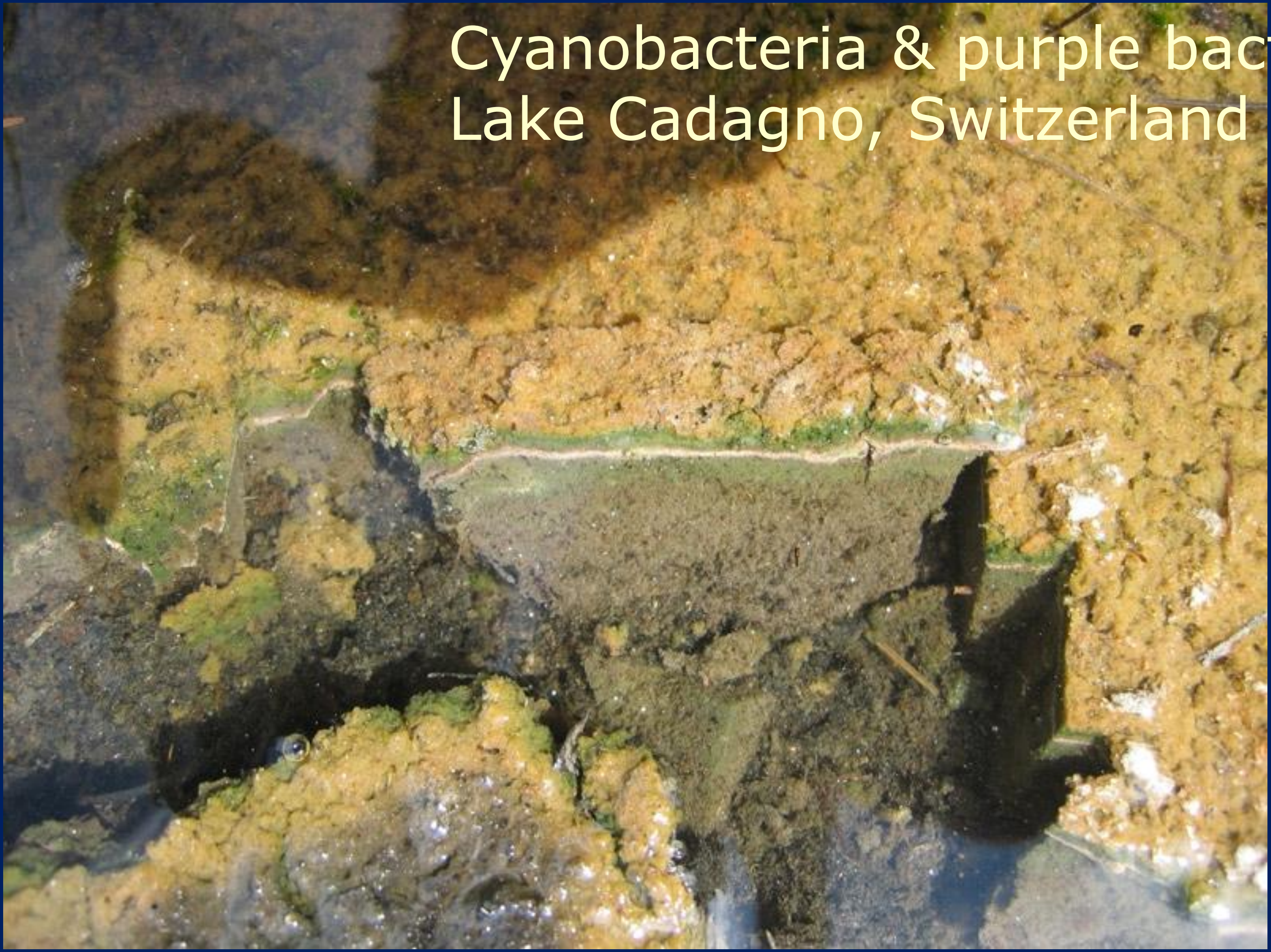

Theoretical Biophysics Group
Beckman Institute
University of Illinois at Urbana-Champaign

Side view of LH2 from *Rsp. molischianum*, note the 8-fold symmetry.



Top view of LH2 of *Rps. acidophila*, note the 9-fold symmetry

Cyanobacteria & purple bacteria
Lake Cadagno, Switzerland



www.microbes.org/labs.asp

	ФОТОТрофия			
	Фотоорганотрофы		**Фотолитотрофы**	
Источник С	Орг.соед-я		CO_2	
Донор электронов для восст.коф-тов	Орг.соед-я		H_2S S	H_2O
Акцептор электронов	Бактерио-родопсин	NAD+		NADP+
Обмен	Анаэробный			Аэробный
Локализация	Мембранные системы ЭТЦ (хлорофилл-содержащие ФС, цитохромы, Fe-S-центры, хиноны)			
Ассимиляция энергии	в виде трансмембранного электрохимического потенциала			
Синтез АТФ	Фототрансдукция	Аноксигенный фотосинтез по цикл.схеме		Оксигенный ФС по Z-схеме
	→ окислительное фотофосфорилирование			

Anoxygenic photosynthesis found in:

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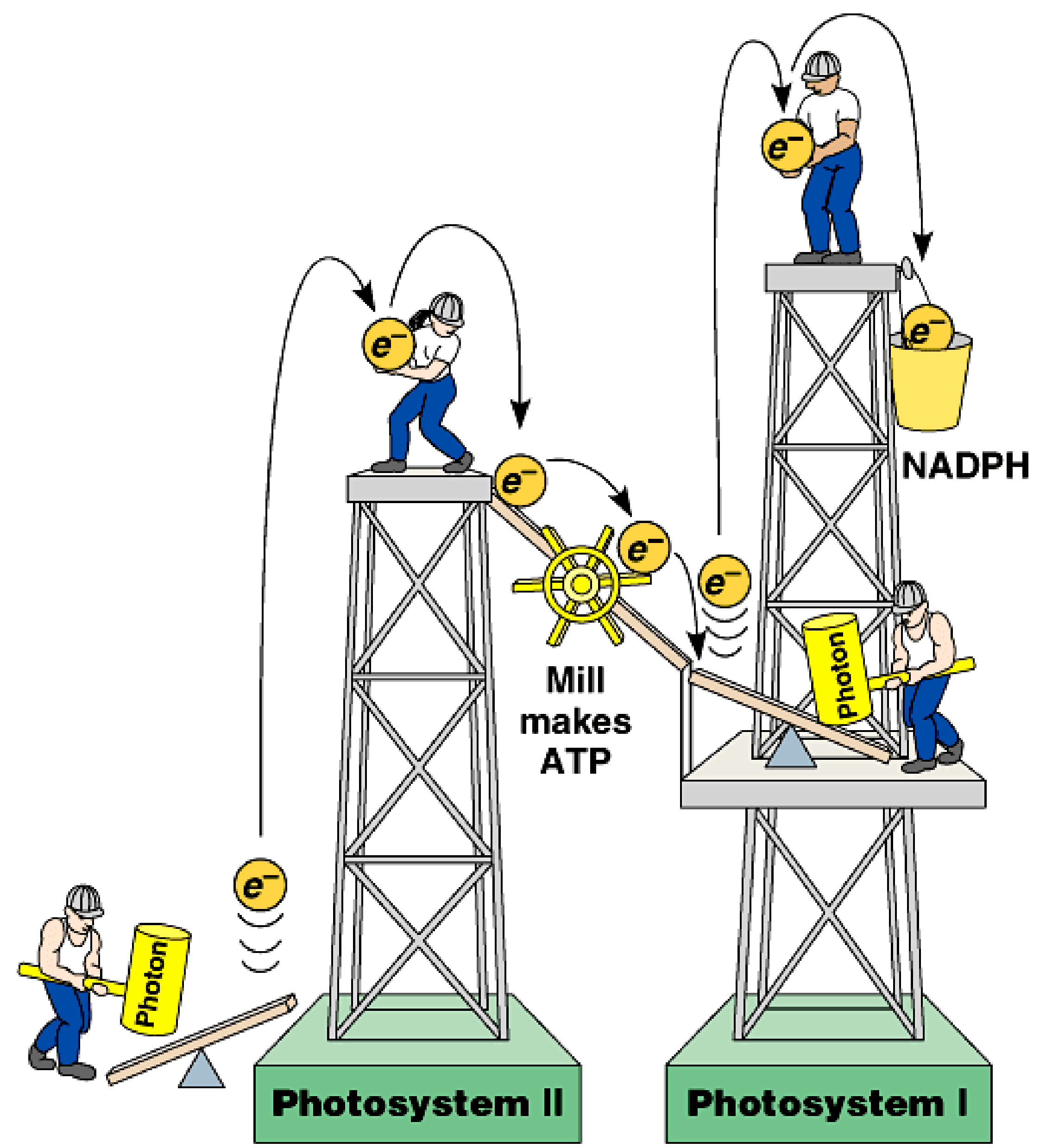
- Purple nonsulfur bacteria (e.g. *Rhodobacter*)
- Green sulfur bacteria (e.g. *Chlorobium*)
- Green nonsulfur bacteria (e.g. *Chloroflexus*)

Oxygenic photosynthesis

- The light reactions use the solar power of photons absorbed by both photosystem I and photosystem II to provide chemical energy in the form of ATP and reducing power in the form of the electrons carried by NADPH.



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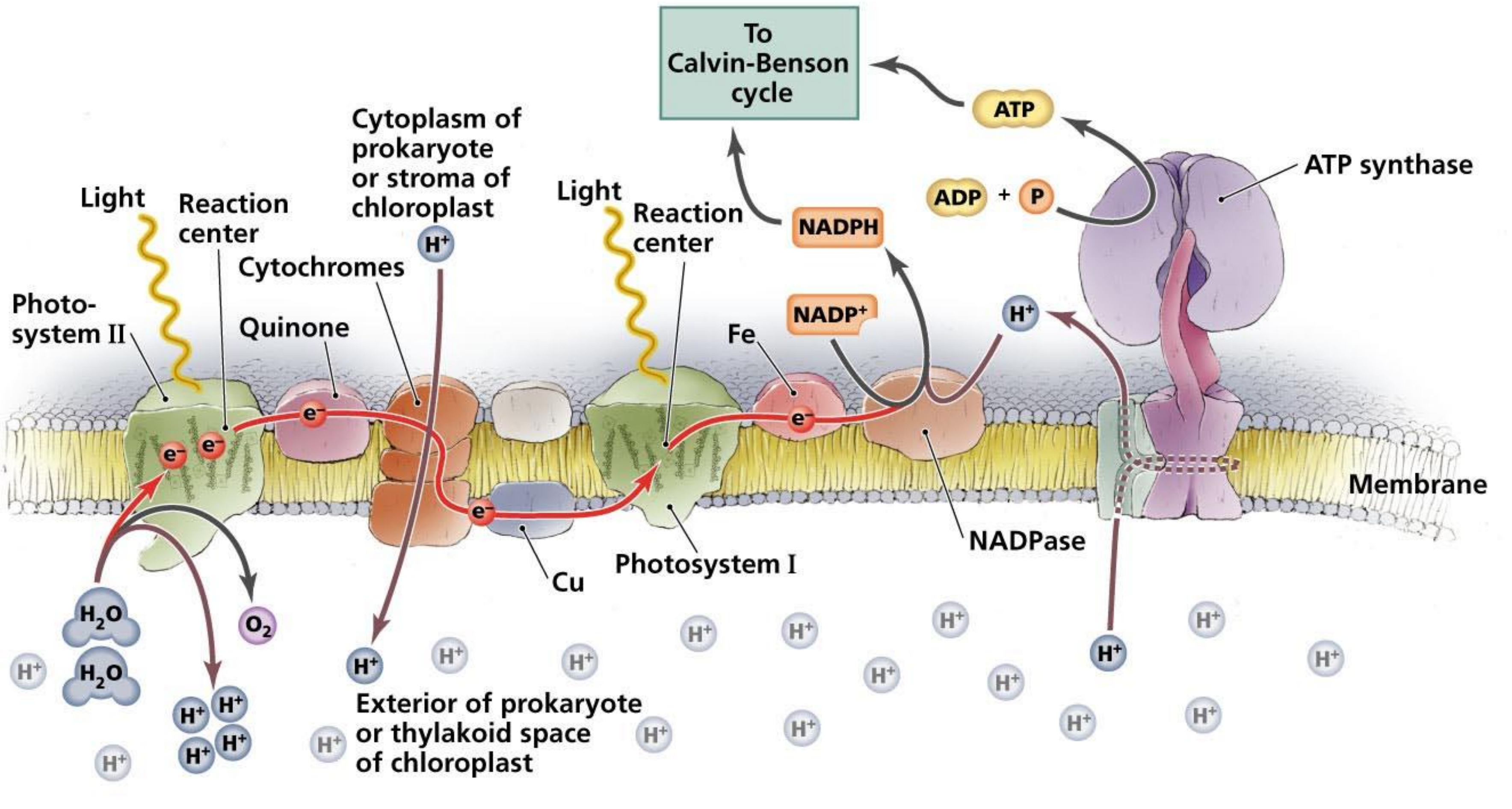
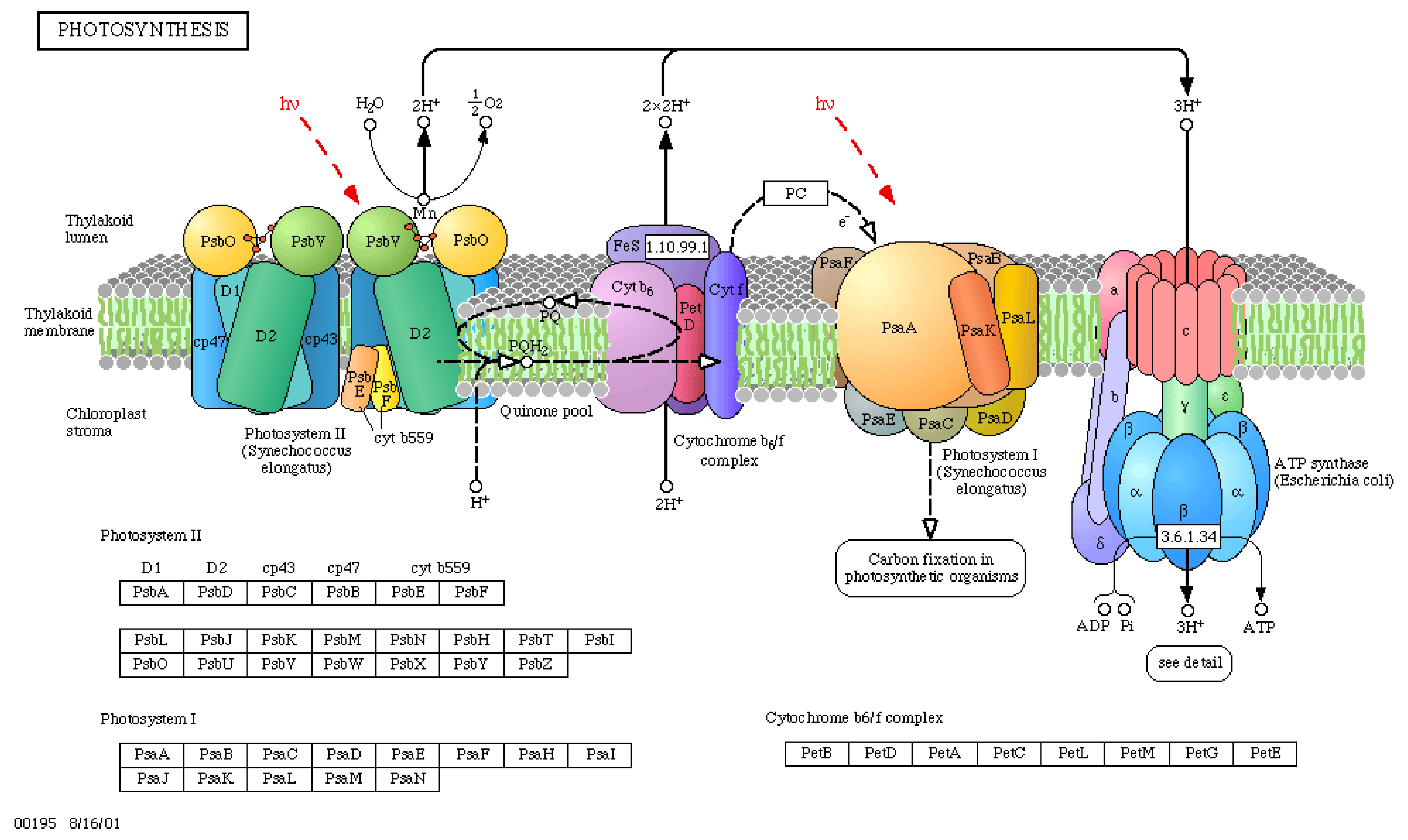
Noncyclic Photophosphorylation



(b) Noncyclic photophosphorylation

Figure 5.28b



Photosystem II

D1	D2	cp43	cp47	cyt b559	
PsbA	PsbD	PsbC	PsbB	PsbE	PsbF

PsbL	PsbJ	PsbK	PsbM	PsbN	PsbH	PsbT	PsbI
PsbO	PsbU	PsbV	PsbW	PsbX	PsbY	PsbZ	

Photosystem I

PsaA	PsaB	PsaC	PsaD	PsaE	PsaF	PsaH	PsaI
PsaJ	PsaK	PsaL	PsaM	PsaN			

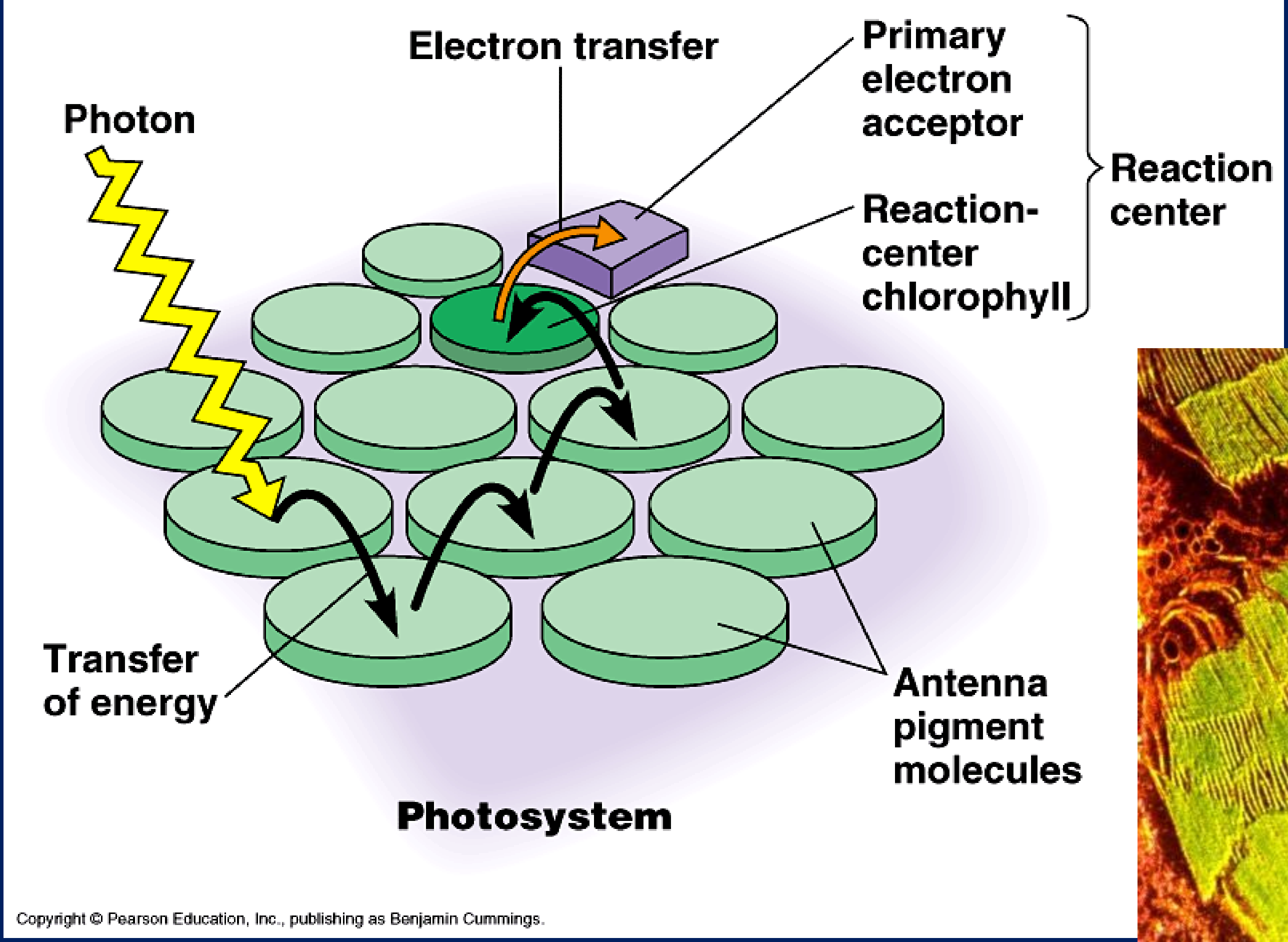
Cytochrome b6/f complex

PetB	PetD	PetA	PetC	PetL	PetM	PetG	PetE

00195 8/16/01

From Kegg: The Koyoto Encyclopedia of Genes and Genomes

Light harvesting (antenna)


Electron transfer
Primary electron acceptor
Reaction-center chlorophyll
Reaction center
Photon
Transfer of energy
Antenna pigment molecules
Photosystem

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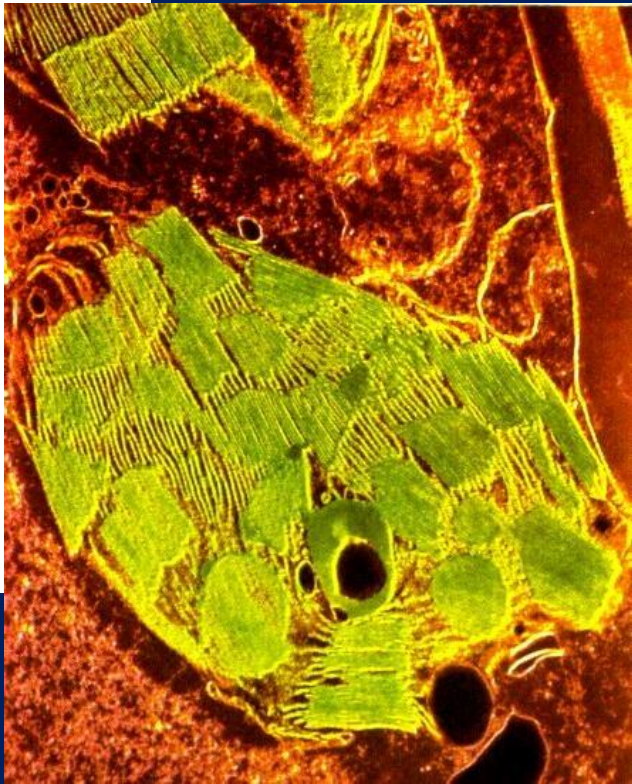
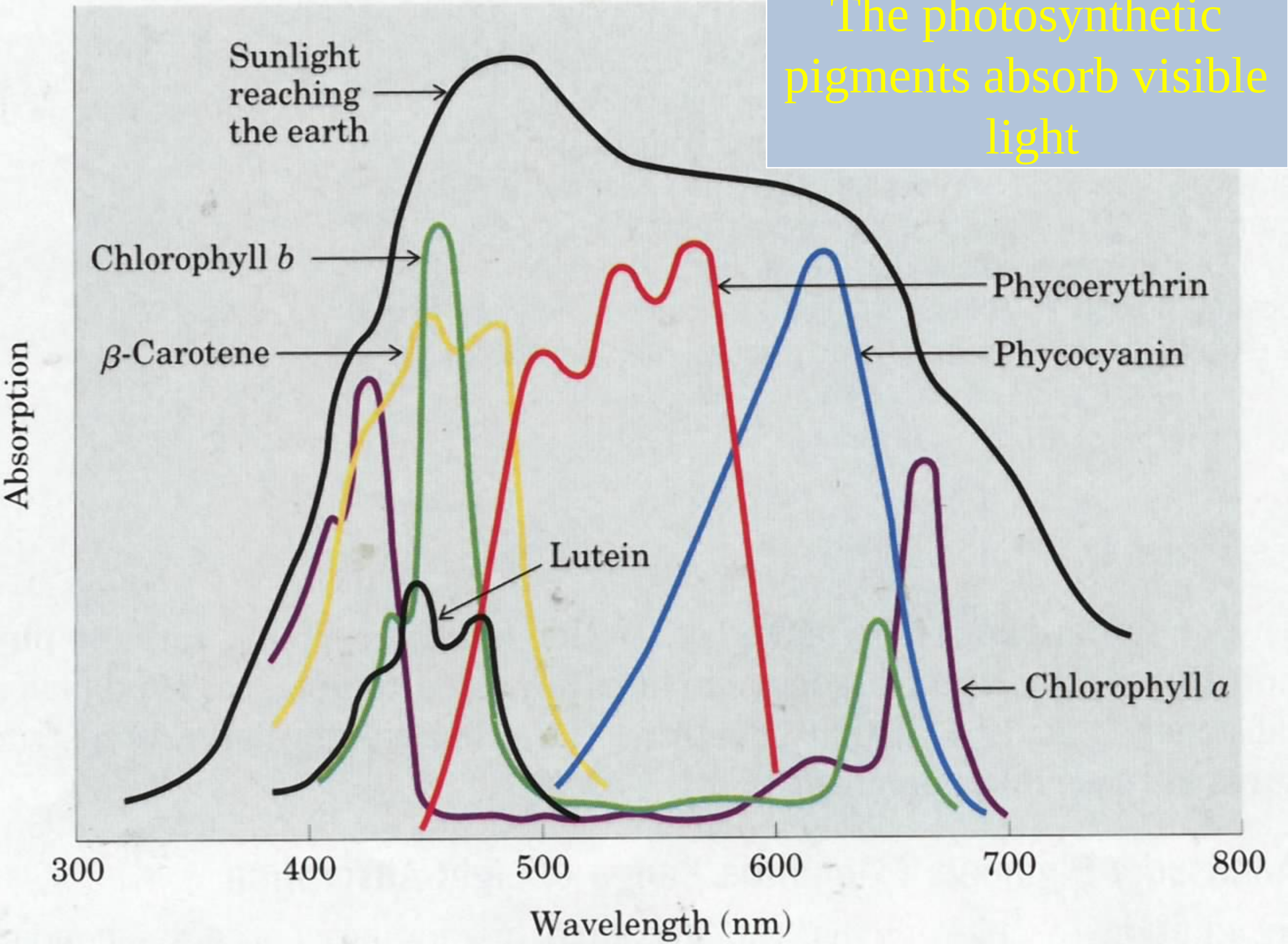
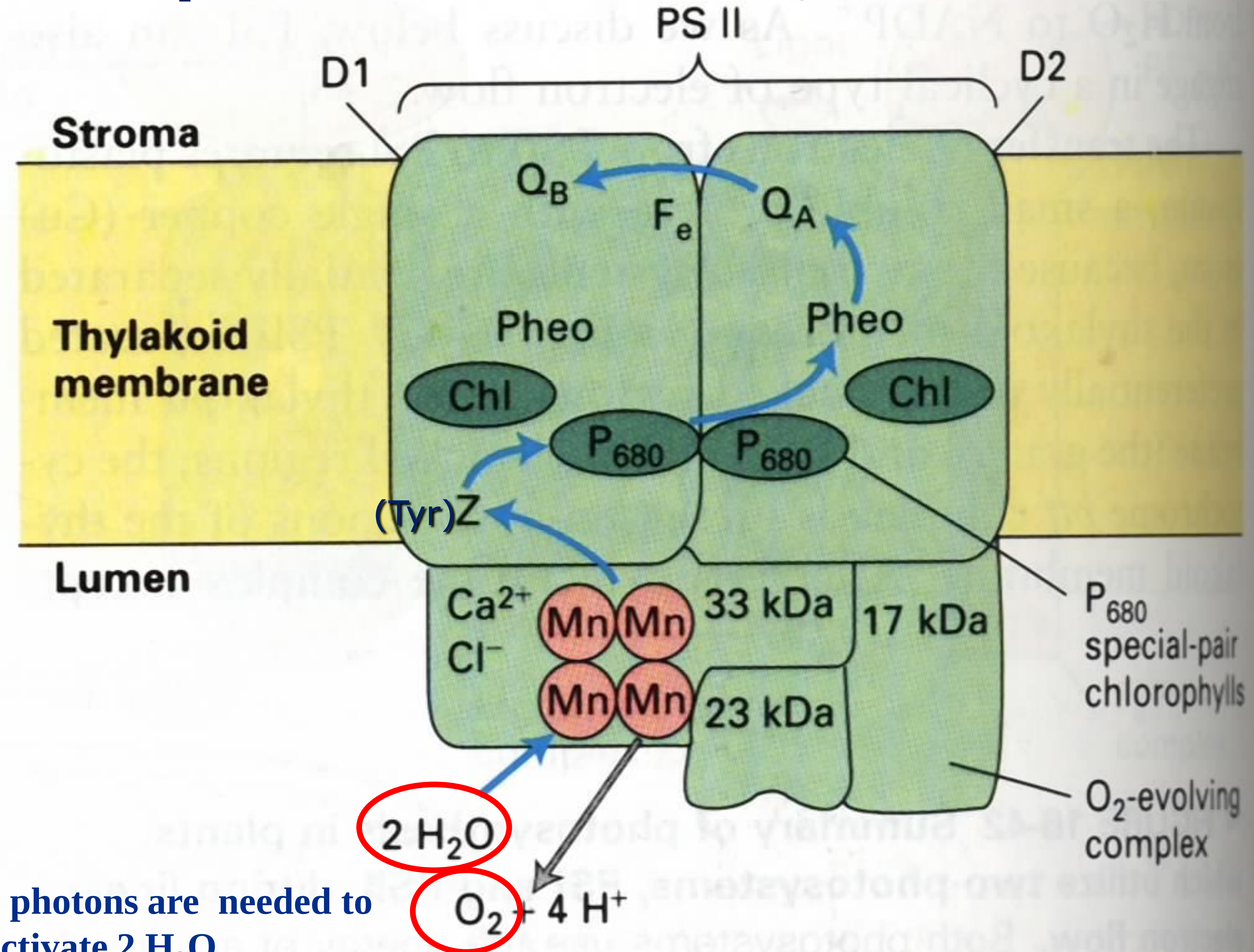


The photosynthetic pigments absorb visible light

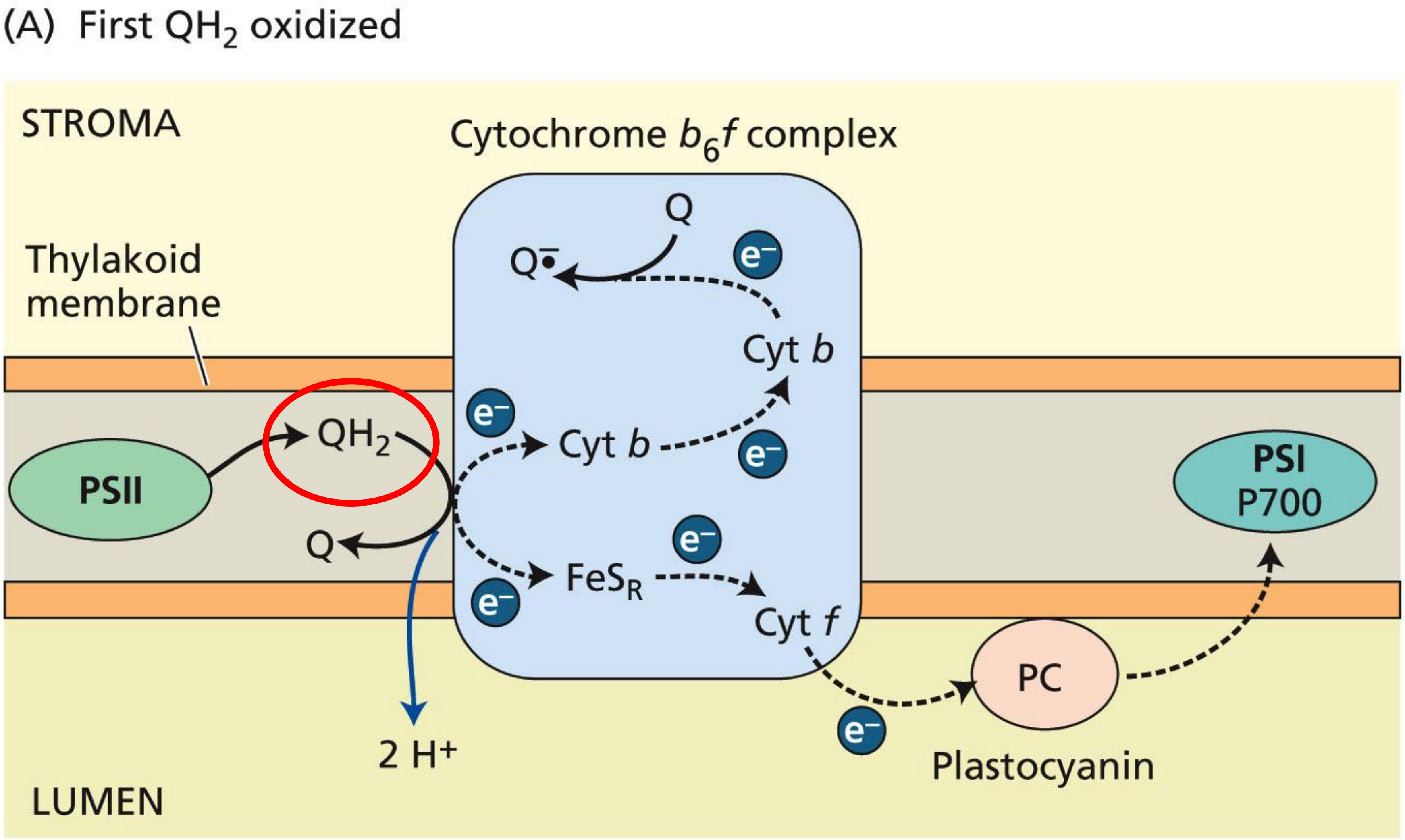


H_2O is the final e^- donor for PSII in higher plants



4 photons are needed to activate 2 H_2O

Mechanism of electron and proton transfer in cytochrome b_6f complex



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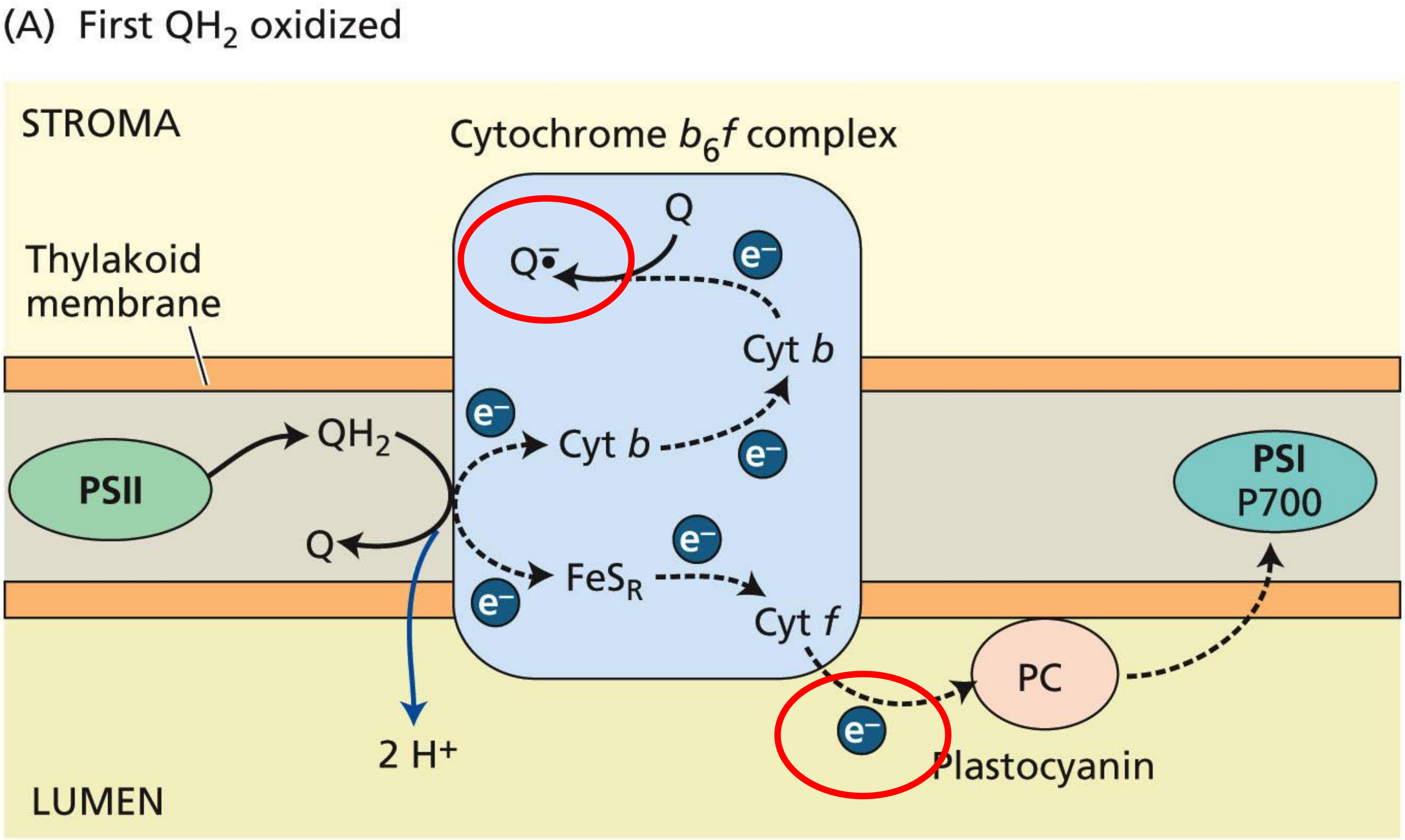
Mechanism of electron and proton transfer in cytochrome b_6f complex



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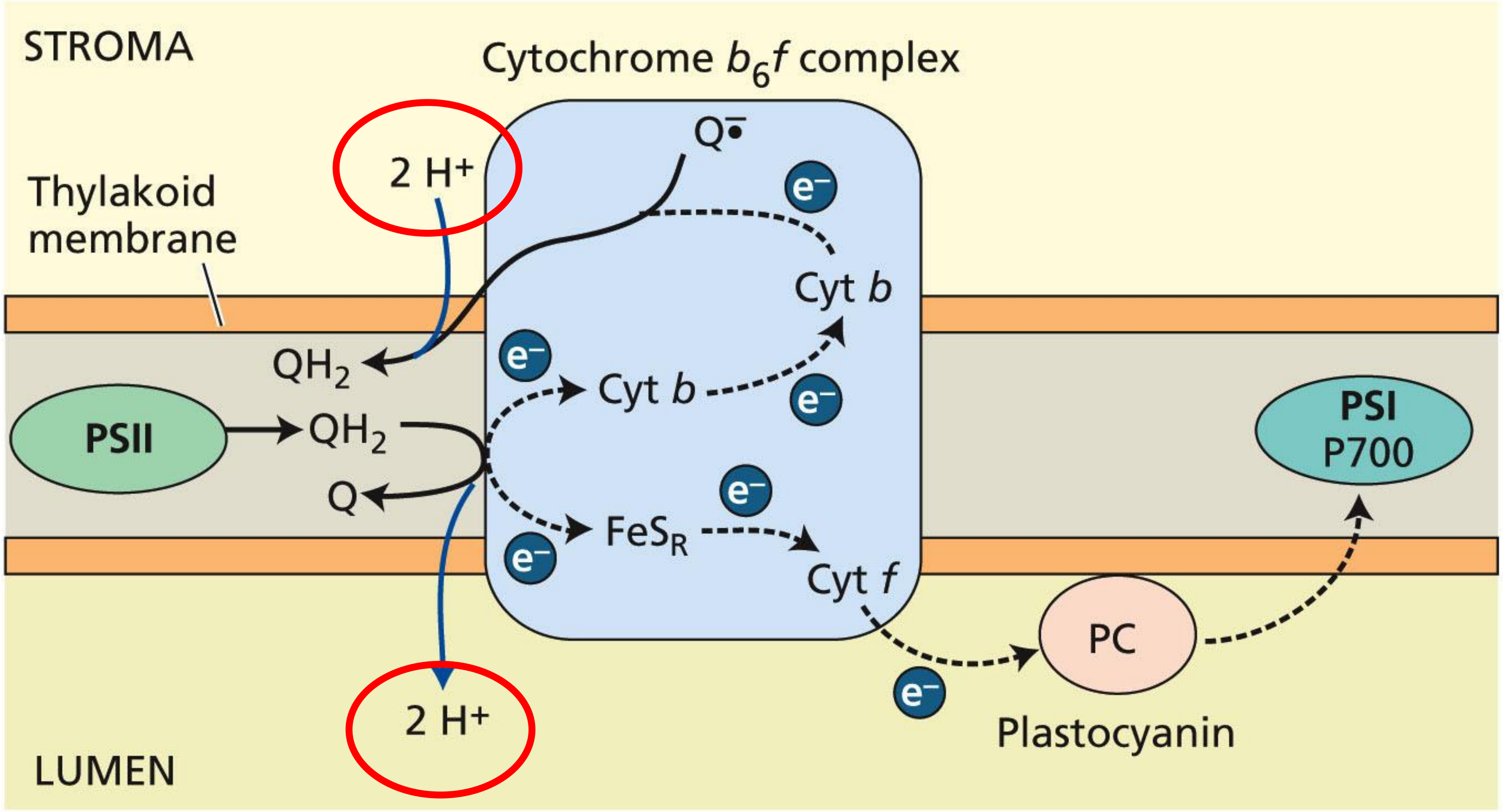
(B) Second QH_2 oxidized



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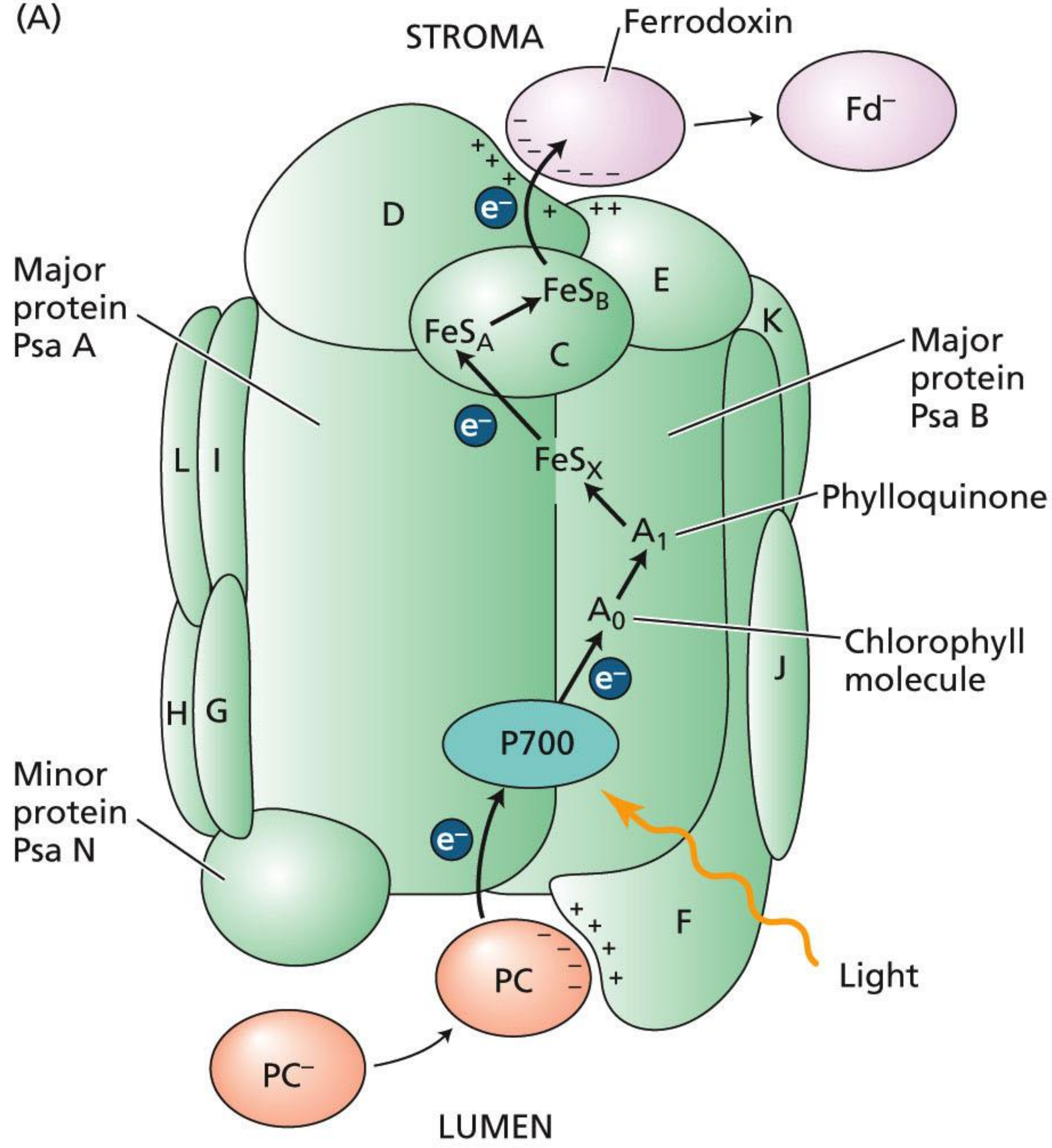
Structure of photosystem I



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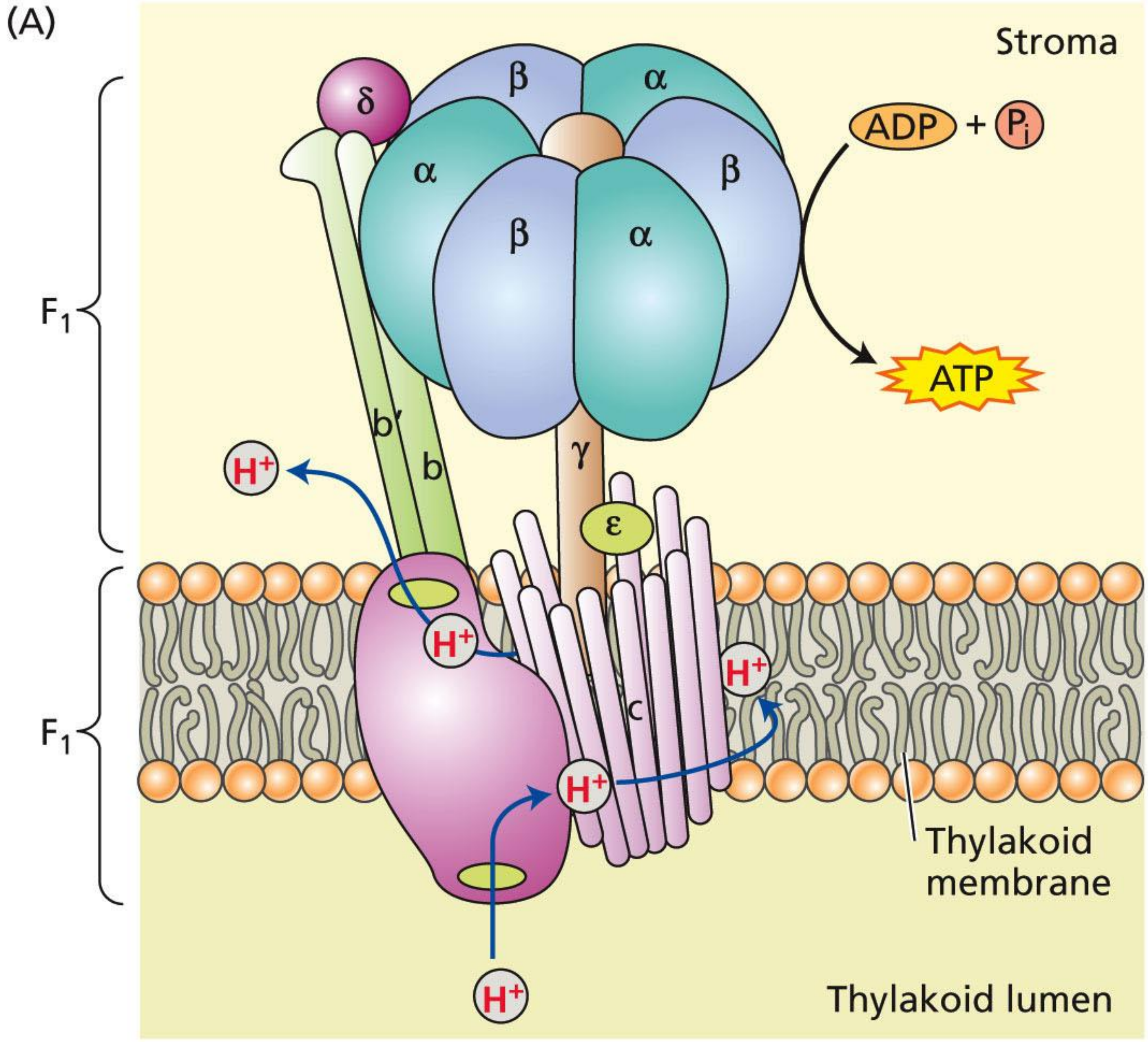
Subunit composition (A) of chloroplast F1F$_0$ ATP synthase



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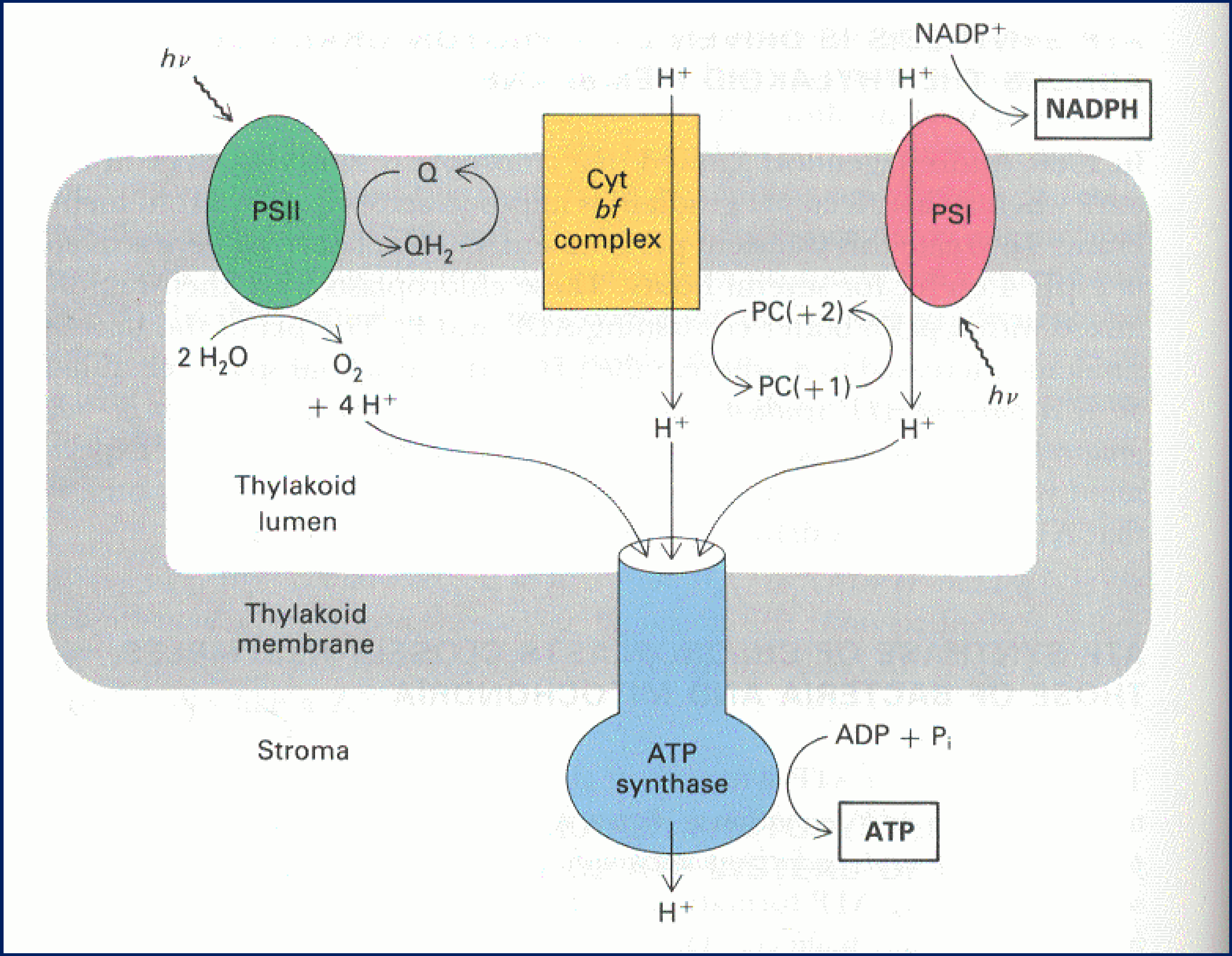
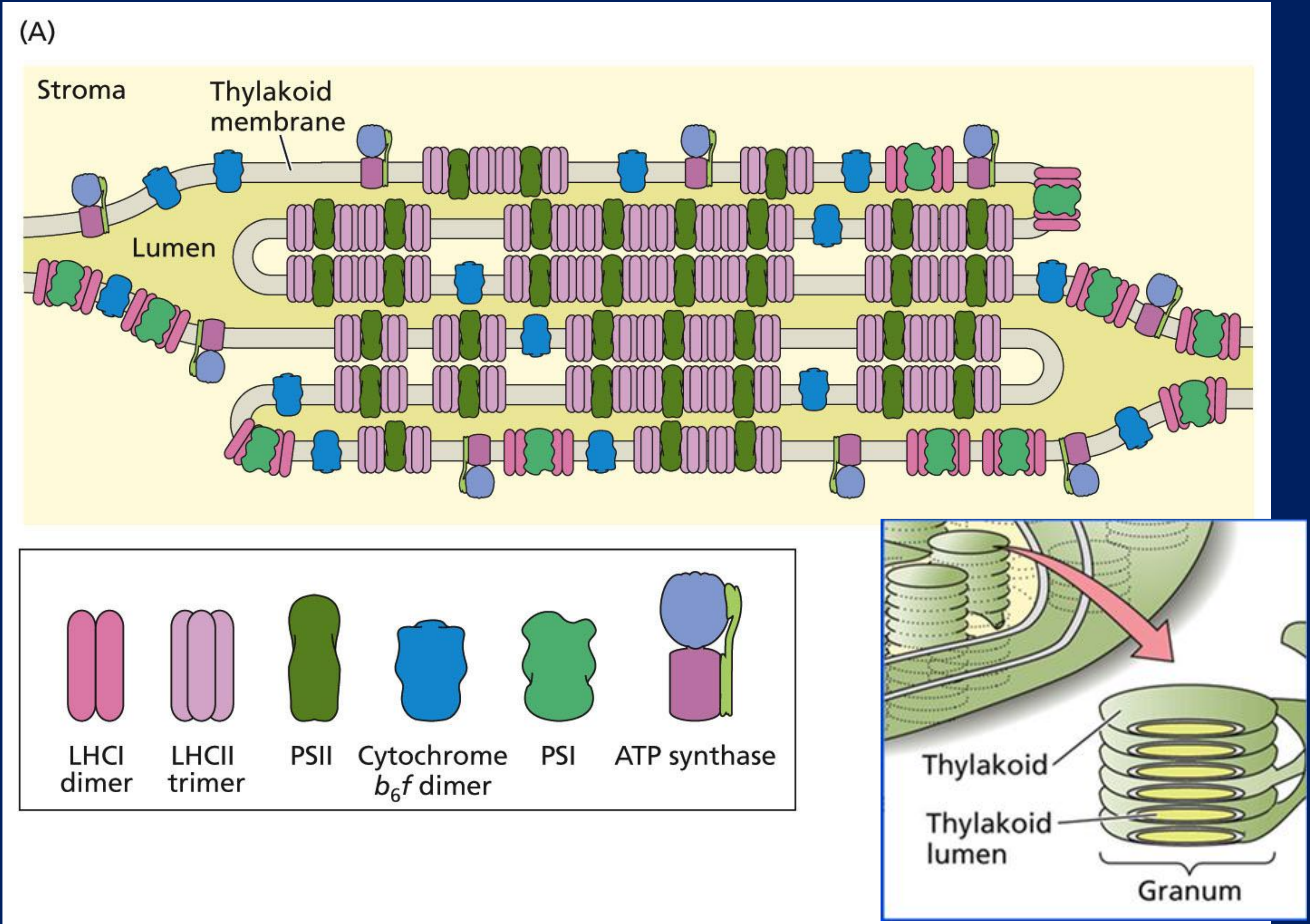
Связь синтеза АТФ и перекачки H+ при фотосинтезе



Organization and structure of the four major protein complexes



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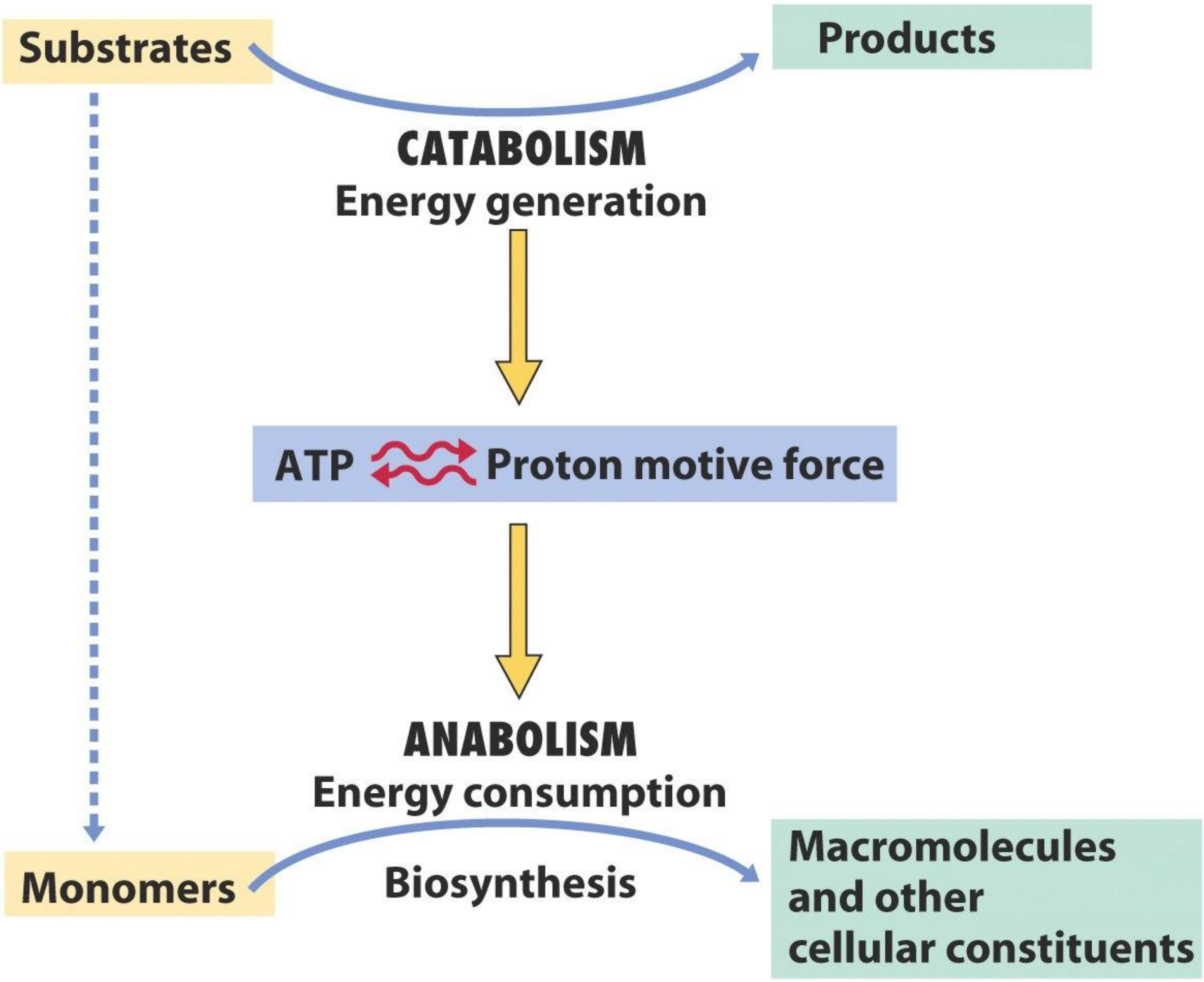
Metabolic pathways

- Catabolic linked with energy and structure blocks production: glycolysis, fatty acids oxidation, ketone bodies synthesis, TCA, AA deamination
- Anabolic: gluconeogenesis, fatty acids synthesis (soluble enzymes), polysaccharides synthesis (from activated forms of hexoses such as UDPG), pentoses for nucleic acid synthesis (decarboxylation of hexoses), synthesis of amino acids, nucleosides, non-ribosomal peptide synthesis, synthesis of membrane lipids and cell walls (peptidoglycans, lipopolysaccharides, etc), capsules, pigments and coenzymes.



Substrates

Products

CATABOLISM

Energy generation

ATP ⇄ Proton motive force

ANABOLISM

Energy consumption

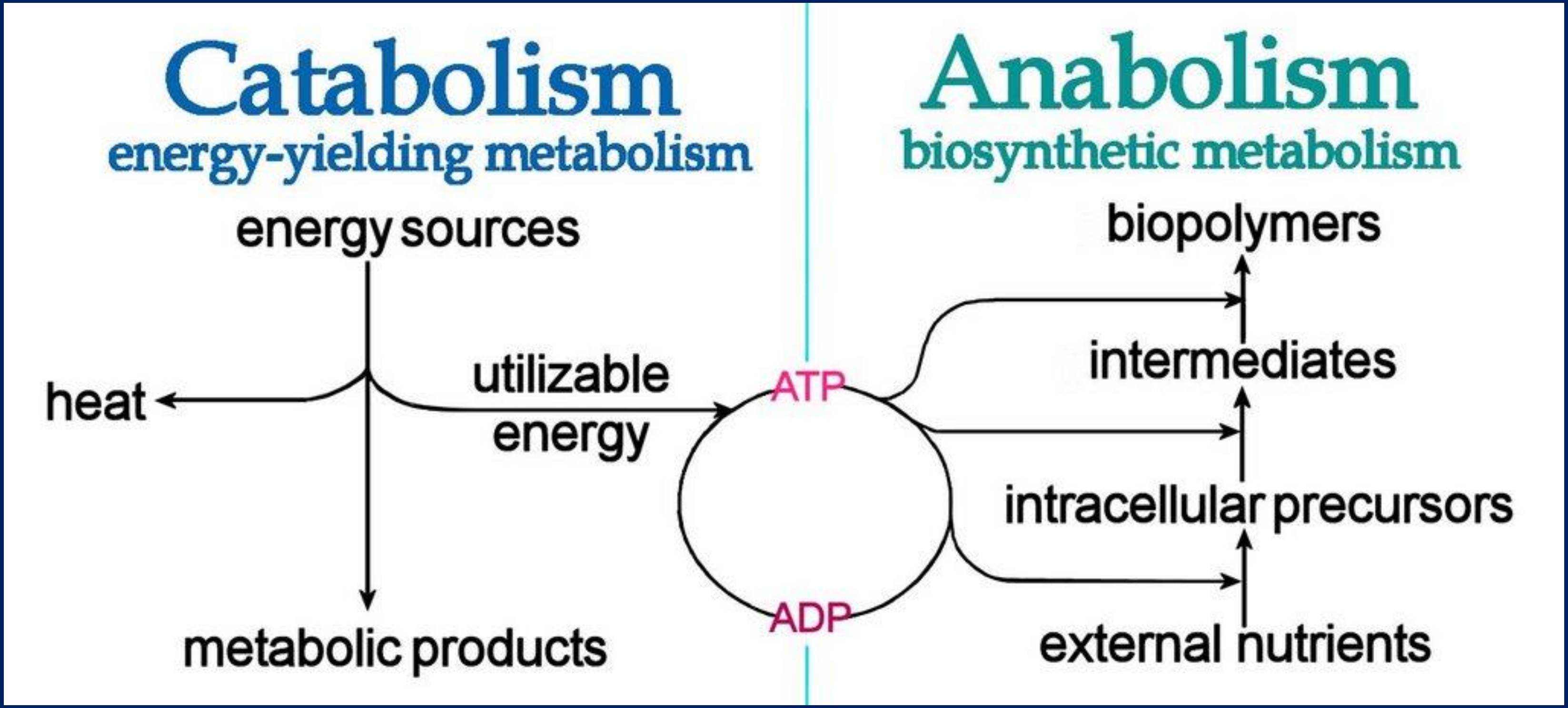
Monomers

Biosynthesis

Macromolecules
and other
cellular constituents

Figure 5-24 Brock Biology of Microorganisms 11/e

© 2006 Pearson Prentice Hall, Inc.



Catabolism

energy-yielding metabolism

Anabolism

biosynthetic metabolism

energy sources

heat

utilizable energy

metabolic products

ATP

ADP

biopolymers

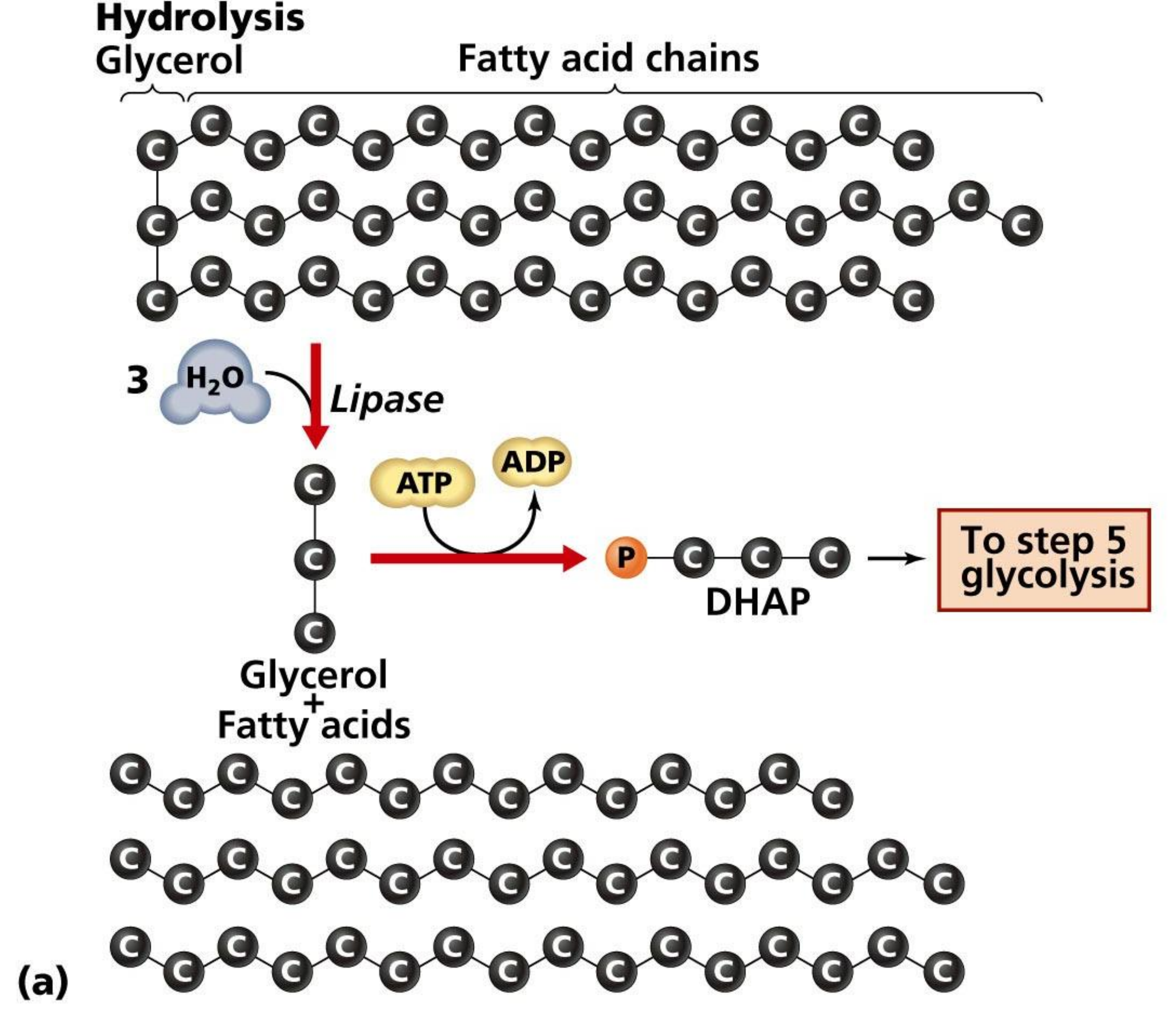
intermediates

intracellular precursors

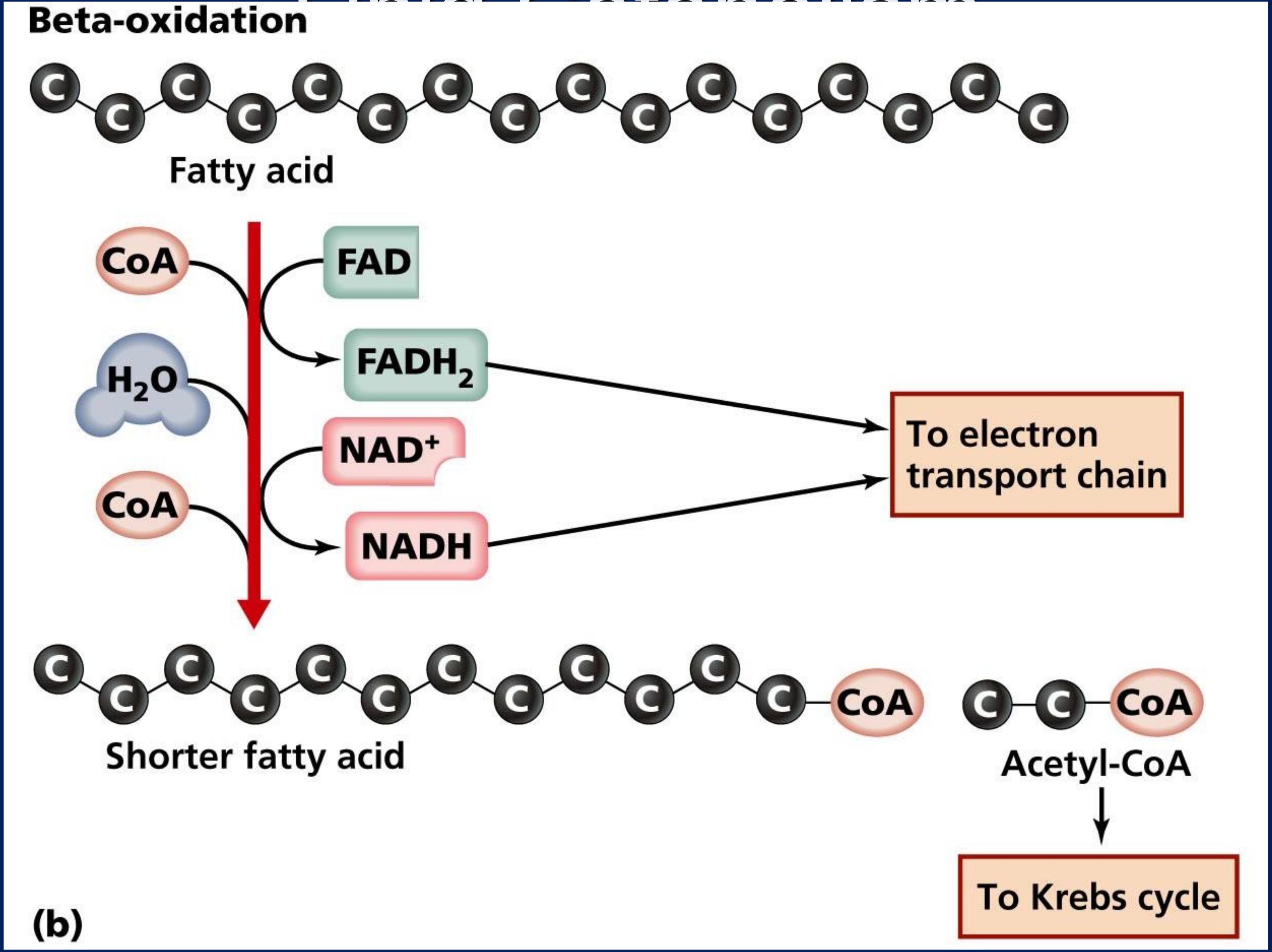
external nutrients

Catabolic Pathways

- Carbohydrate Catabolism
- Lipid Catabolism
- Protein Catabolism
- Nucleotide Catabolism


Hydrolysis
Glycerol
Fatty acid chains
3 H_2O
Lipase
ATP
ADP
P
DHAP
To step 5 glycolysis
Glycerol
+
Fatty acids
(a)

Lipid Catabolism



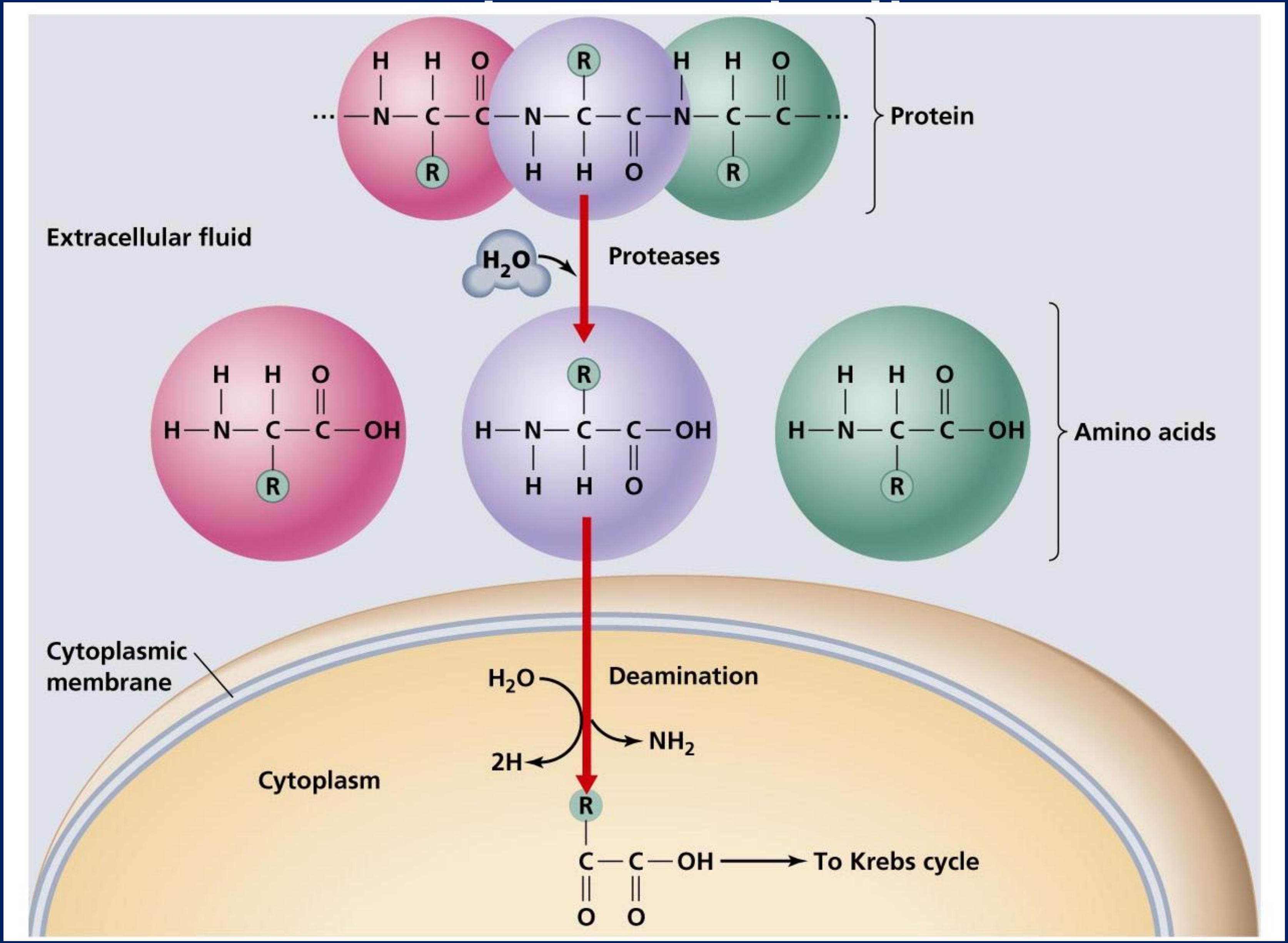

Protein
Extracellular fluid
H_2O
Proteases
Amino acids
Cytoplasmic membrane
H_2O
Deamination
NH_2
2H
Cytoplasm
R
C—C—OH
O O
To Krebs cycle

Figure 5.25

Катаболическая активность прокариот

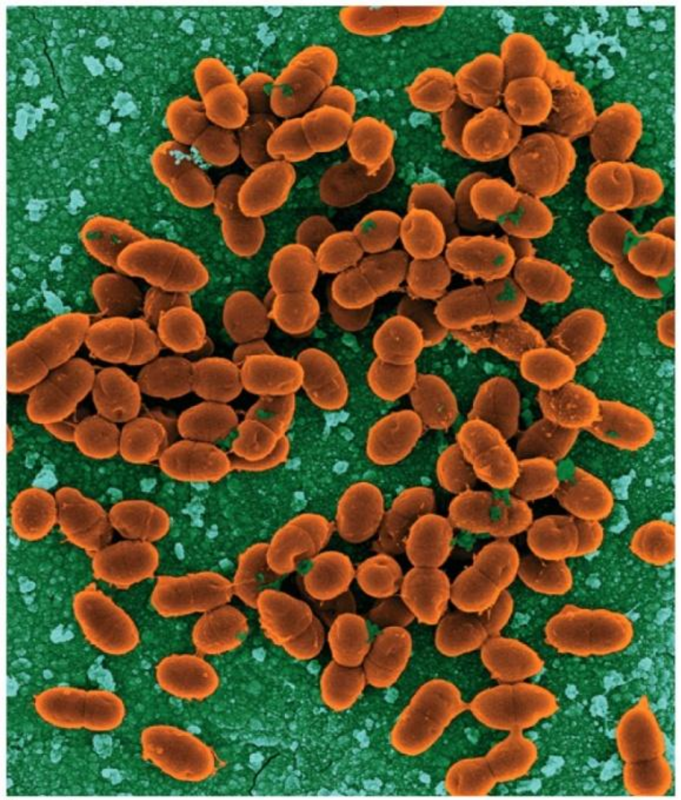


Figure 1-1a
Molecular Cell Biology, Sixth Edition
© 2008 W. H. Freeman and Company

с/к «Биохимия клетки»
Лекция 2-2

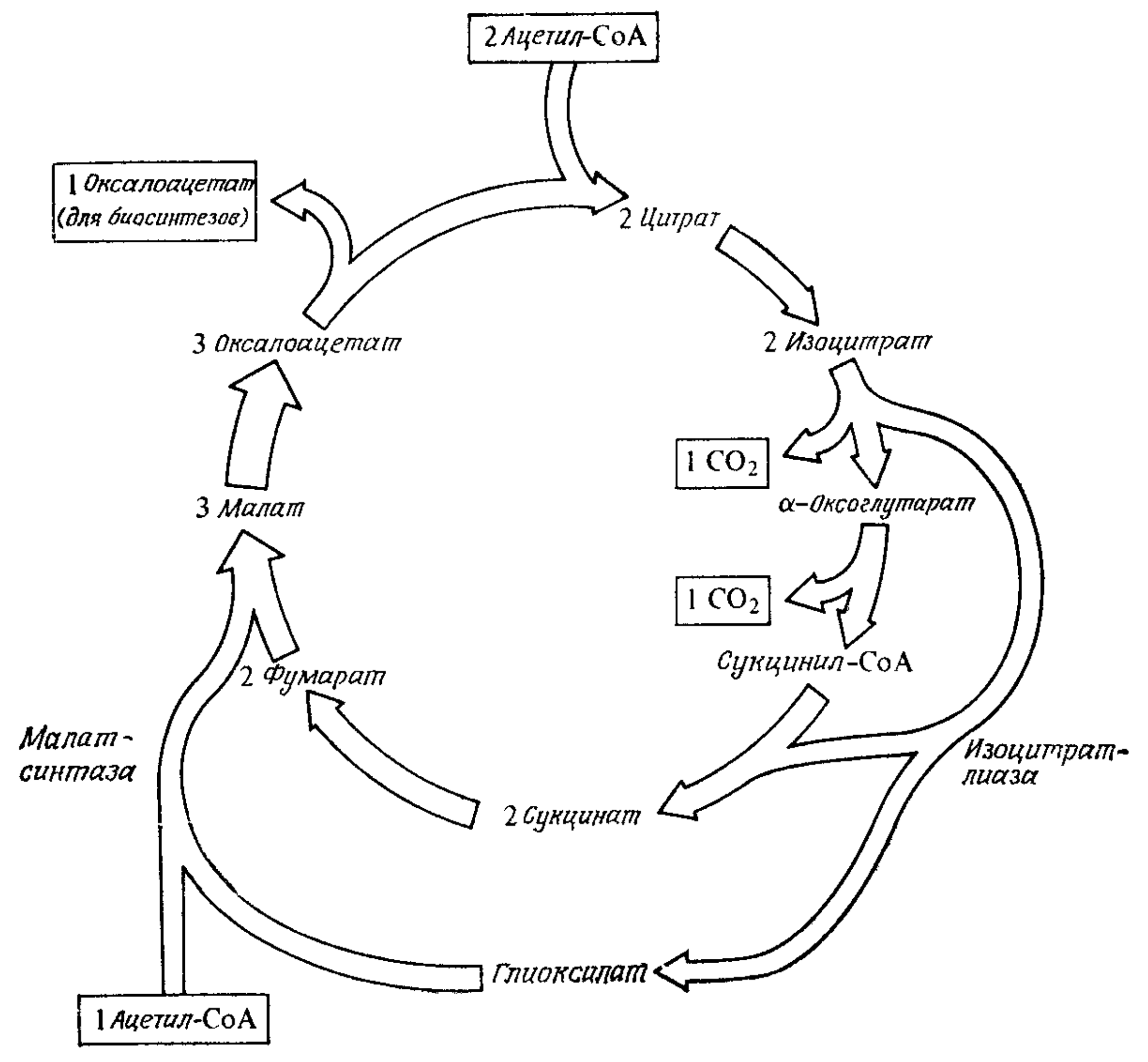
Использование разных субстратов для роста

- Рост на других сахарах
- При росте на фруктозе нужна *1*-фосфофруктокиназа. Из фруктозы с использованием ФЕП образуется фруктозо-*1*-фосфат, который далее фосфорилируется 1-ФФК-зой в Фр1,6-бисфосфат.
- При росте на лактозе синтезируются минимум 5 новых ферментов: лактозопермеаза (перенос) и β-галактозидаза (расщепление лактозы на галактозу и глюкозу). Галактоза затем индуцирует синтез галактокиназы, уридилтрансферазы (переносит УДФ с УДФ-глюкозы на УДФ-галактозу) и УДФ-глюкоза-эпимеразы, которая превращает УДФ-галактозу в УДФ-глюкозу.

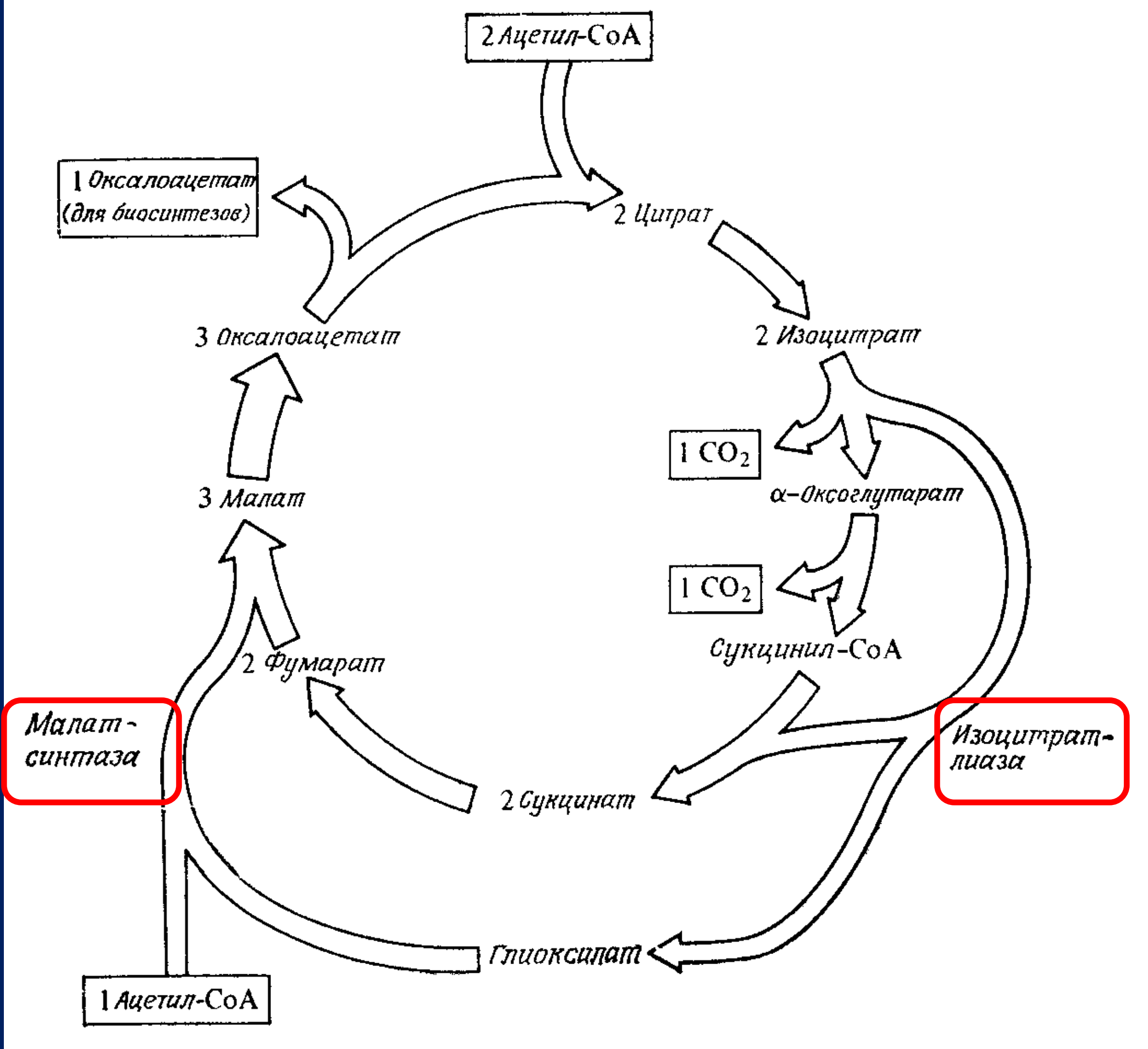
Рост на органических кислотах

- При росте на среде с пируватом нужна фосфоенолпируват-синтетаза (синтез ФЕП из пирувата и АТФ) и фосфоенолпируват-карбоксилаза (синтез оксалоацетата) для анаплеротических реакций
- При росте на L-малате для образования пирувата требуется малатдегидрогеназа декарбоксилирующая.

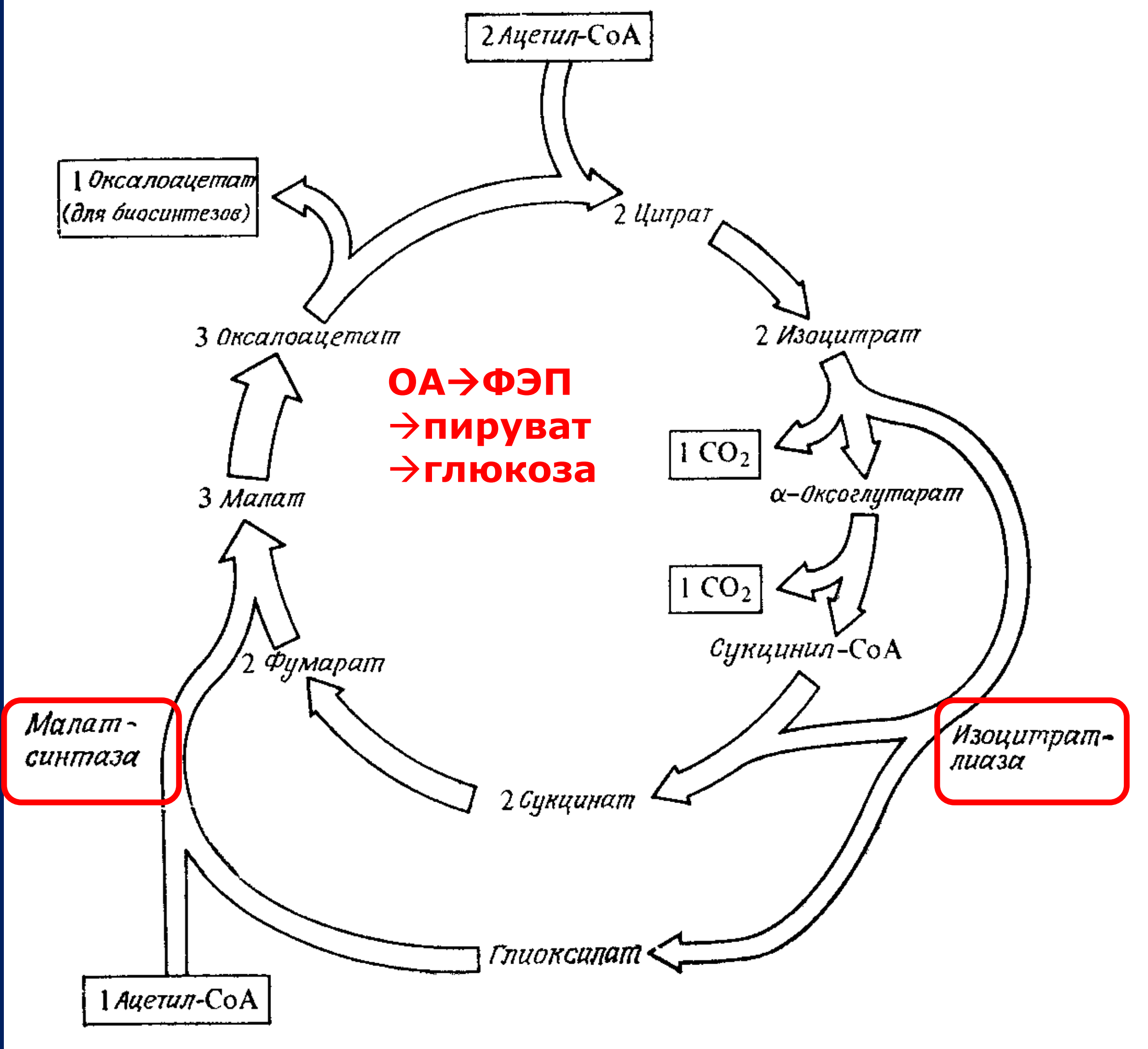
При росте на средах с ацетатом или жирными кислотами: Жирные кислоты распадаются путем β-окисления. Бактерии, растущие на этих соединениях, используют глиоксилатный цикл для образования дикарбоновых кислот



При росте на средах с ацетатом или жирными кислотами: Жирные кислоты распадаются путем β-окисления. Бактерии, растущие на этих соединениях, используют глиоксилатный цикл для образования дикарбоновых кислот

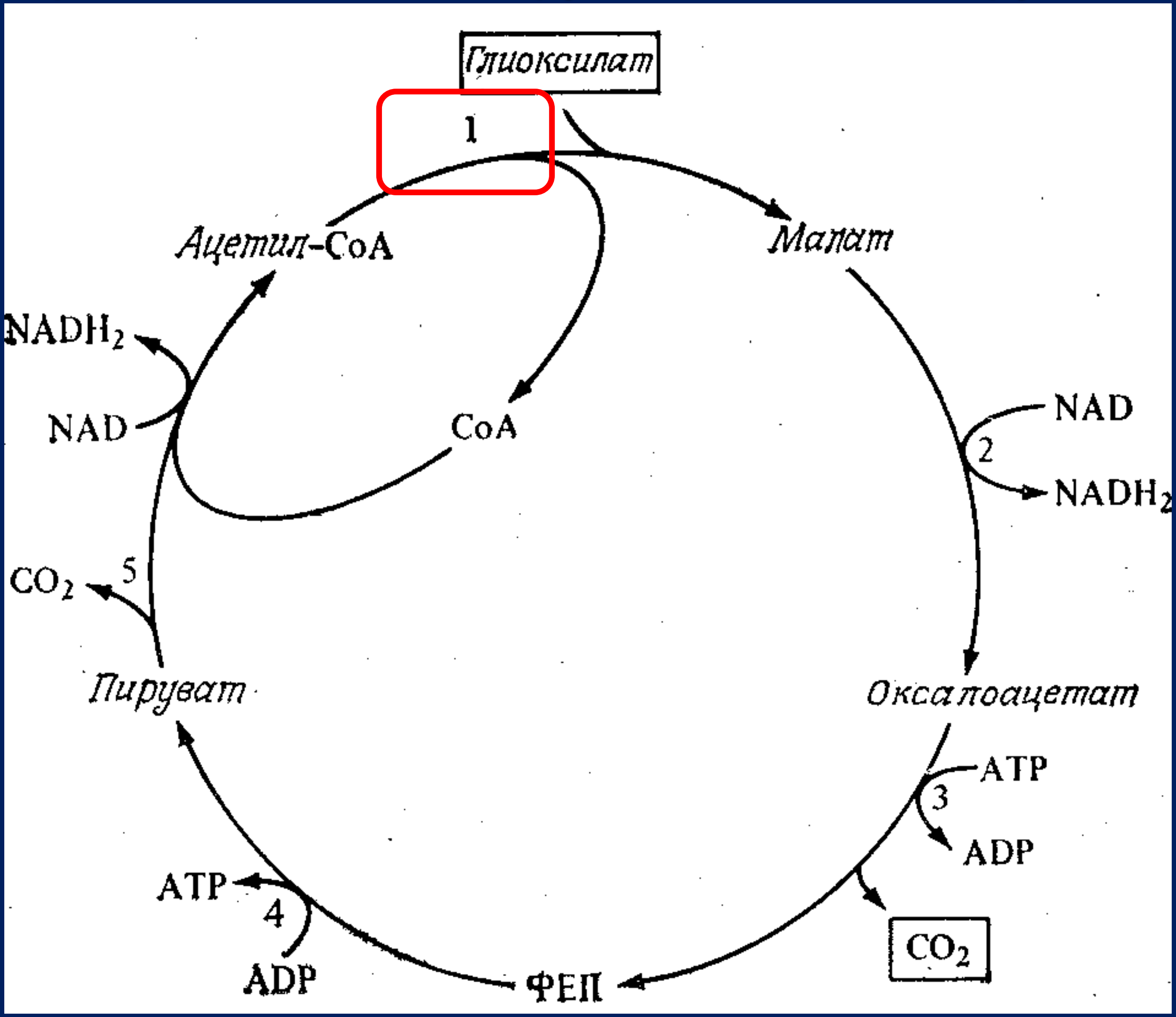


При росте на средах с ацетатом или жирными кислотами: Жирные кислоты распадаются путем β-окисления. Бактерии, растущие на этих соединениях, используют глиоксилатный цикл для образования дикарбоновых кислот



ОА→ФЭП →пируват →глюкоза

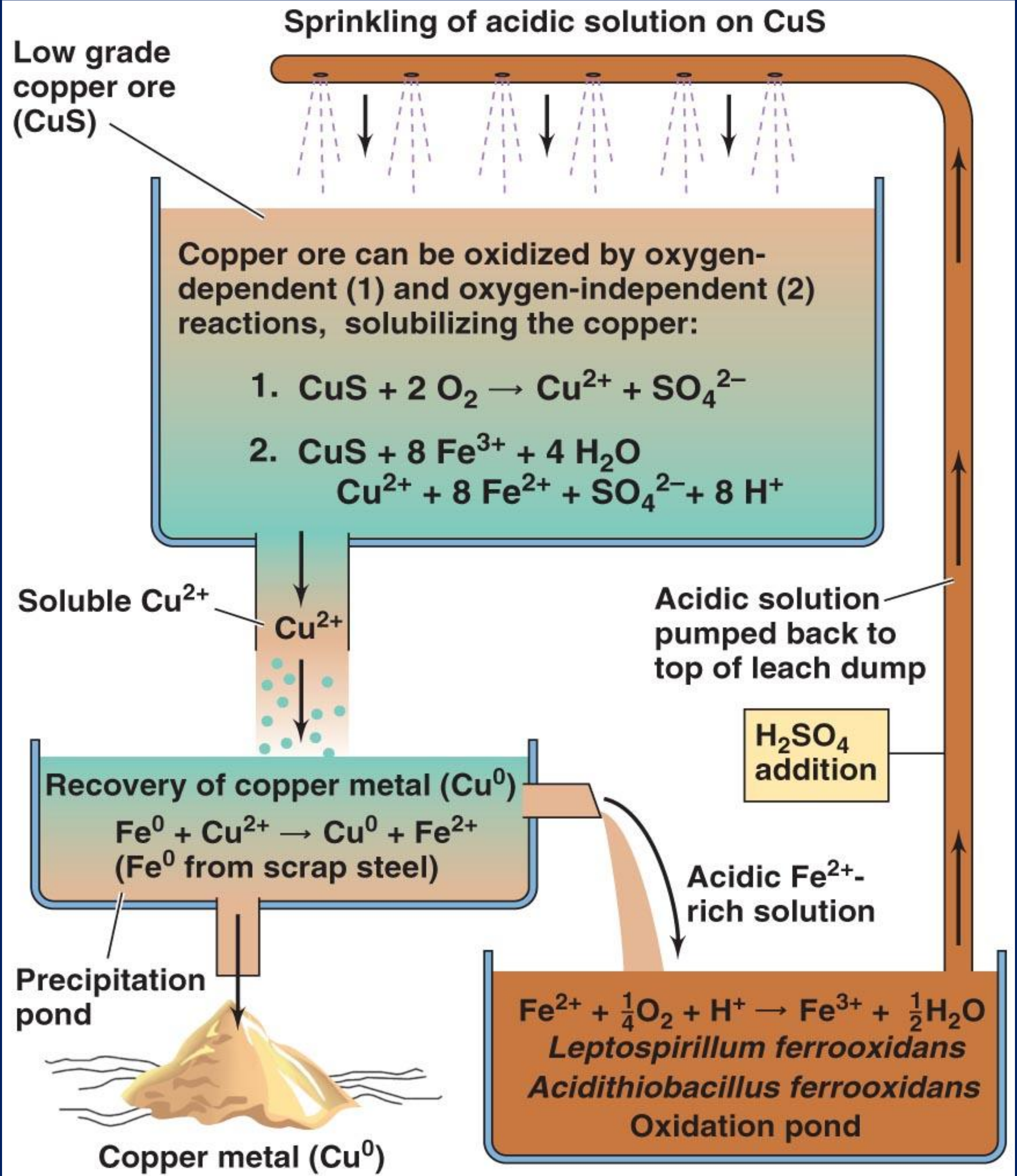
Рост на нуклеотидах. Глиоксилат образуется как продукт разрушения пуриновых оснований; он окисляется далее: **Цикл дикарбоновых кислот**. 1 — малат-синтаза; *2*—малатДГ; *3—ФЕП*—карбоксикиназа; *4*—пируваткиназа; 5—пируватДГ комплекс



Microbial Bioremediation

- Microbial Leaching of Ores
- Mercury and Heavy Metal Transformations
- Petroleum Biodegradation
- Biodegradation of Xenobiotics

Arrangement of a Leaching Pile and Reactions



Sprinkling of acidic solution on CuS

Low grade copper ore (CuS)

Copper ore can be oxidized by oxygen-dependent (1) and oxygen-independent (2) reactions, solubilizing the copper:

1. $CuS + 2\,O_2 \rightarrow Cu^{2+} + SO_4^{2-}$
2. $CuS + 8\,Fe^{3+} + 4\,H_2O$
   $Cu^{2+} + 8\,Fe^{2+} + SO_4^{2-} + 8\,H^+$

Soluble Cu^{2+}

Cu^{2+}

Acidic solution pumped back to top of leach dump

H_2SO_4 addition

Recovery of copper metal (Cu^0)

$Fe^0 + Cu^{2+} \rightarrow Cu^0 + Fe^{2+}$

(Fe^0 from scrap steel)

Acidic Fe^{2+}-rich solution

Precipitation pond

$Fe^{2+} + \frac{1}{4}O_2 + H^+ \rightarrow Fe^{3+} + \frac{1}{2}H_2O$

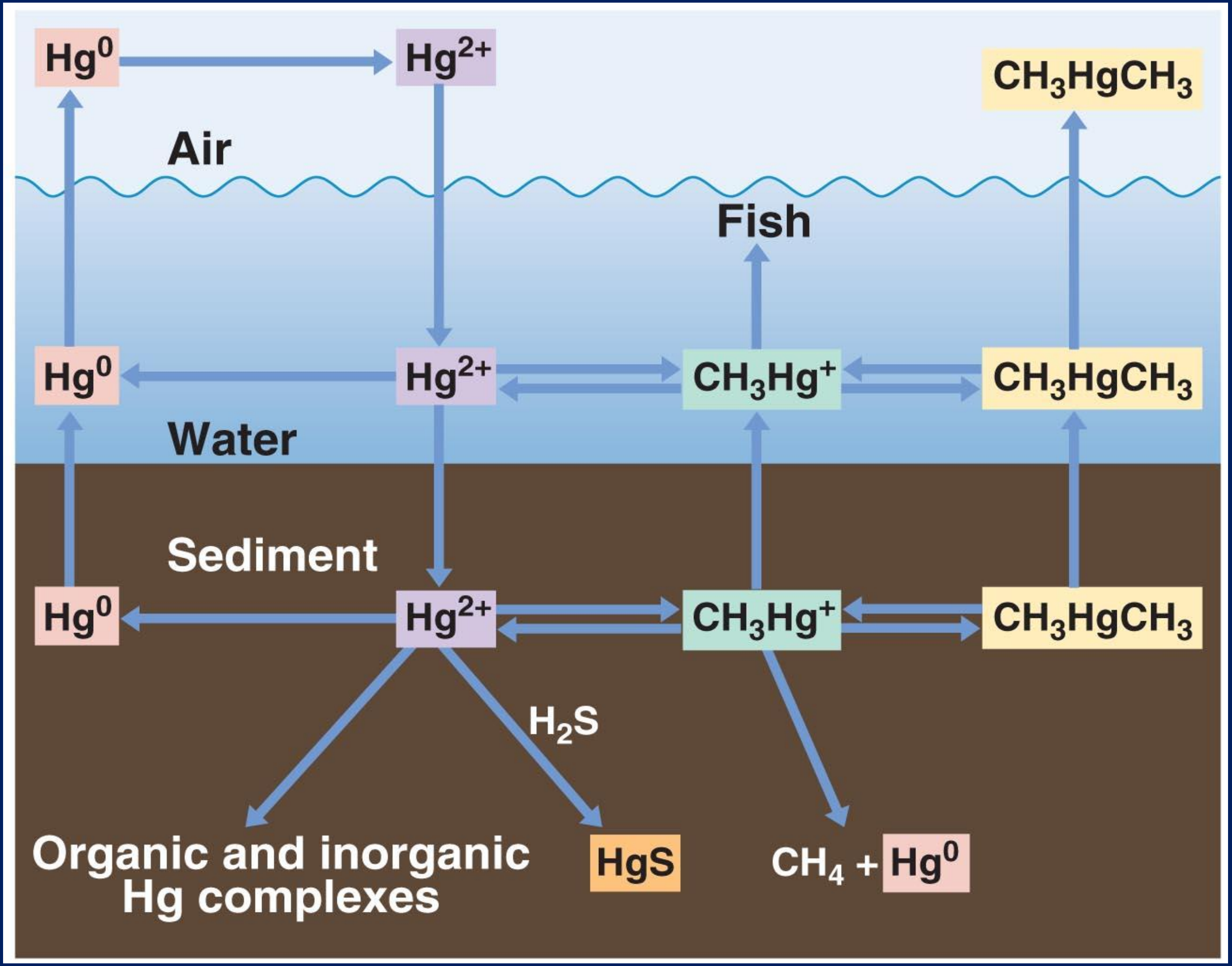
Leptospirillum ferrooxidans

Acidithiobacillus ferrooxidans

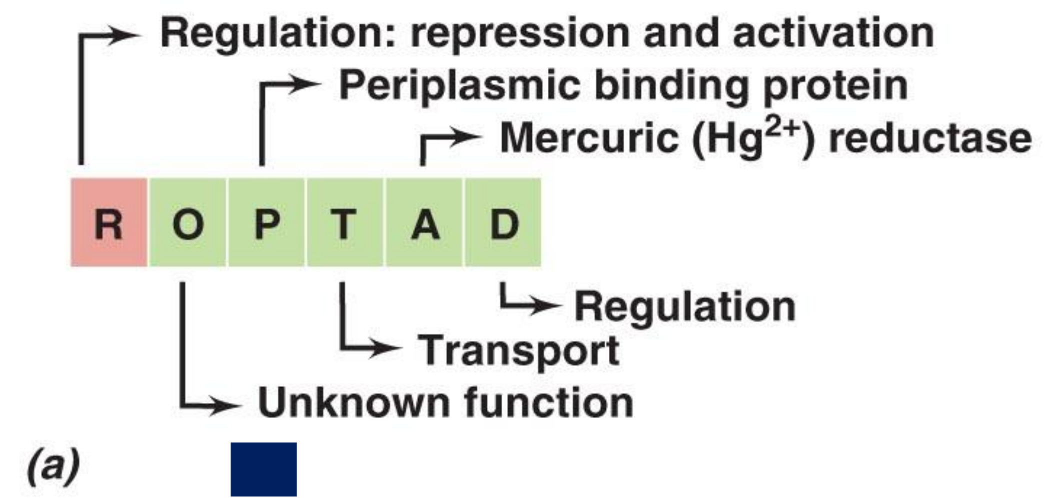
Oxidation pond

Copper metal (Cu^0)

Biogeochemical Cycling of Mercury

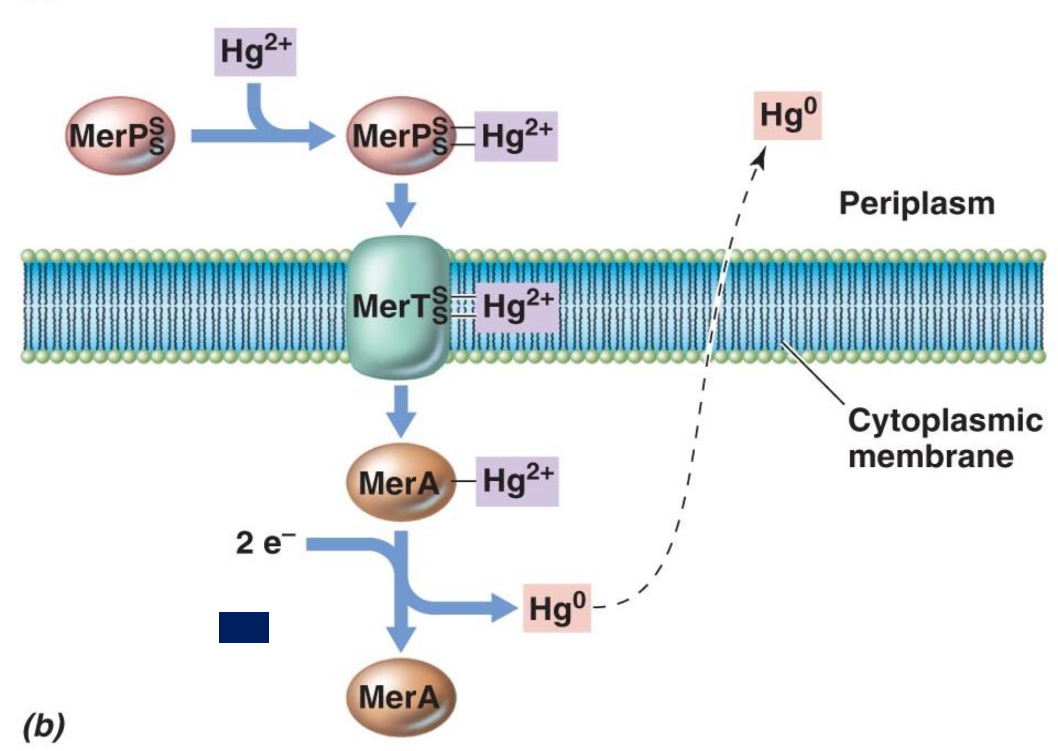


Mechanism of Hg^{2+} Reduction to Hg^{o} in *P. aeruginosa*


Regulation: repression and activation
Periplasmic binding protein
Mercuric (Hg^{2+}) reductase
R
O
P
T
A
D
Regulation
Transport
Unknown function
(a)

[redacted]

The *mer operon*



[redacted]

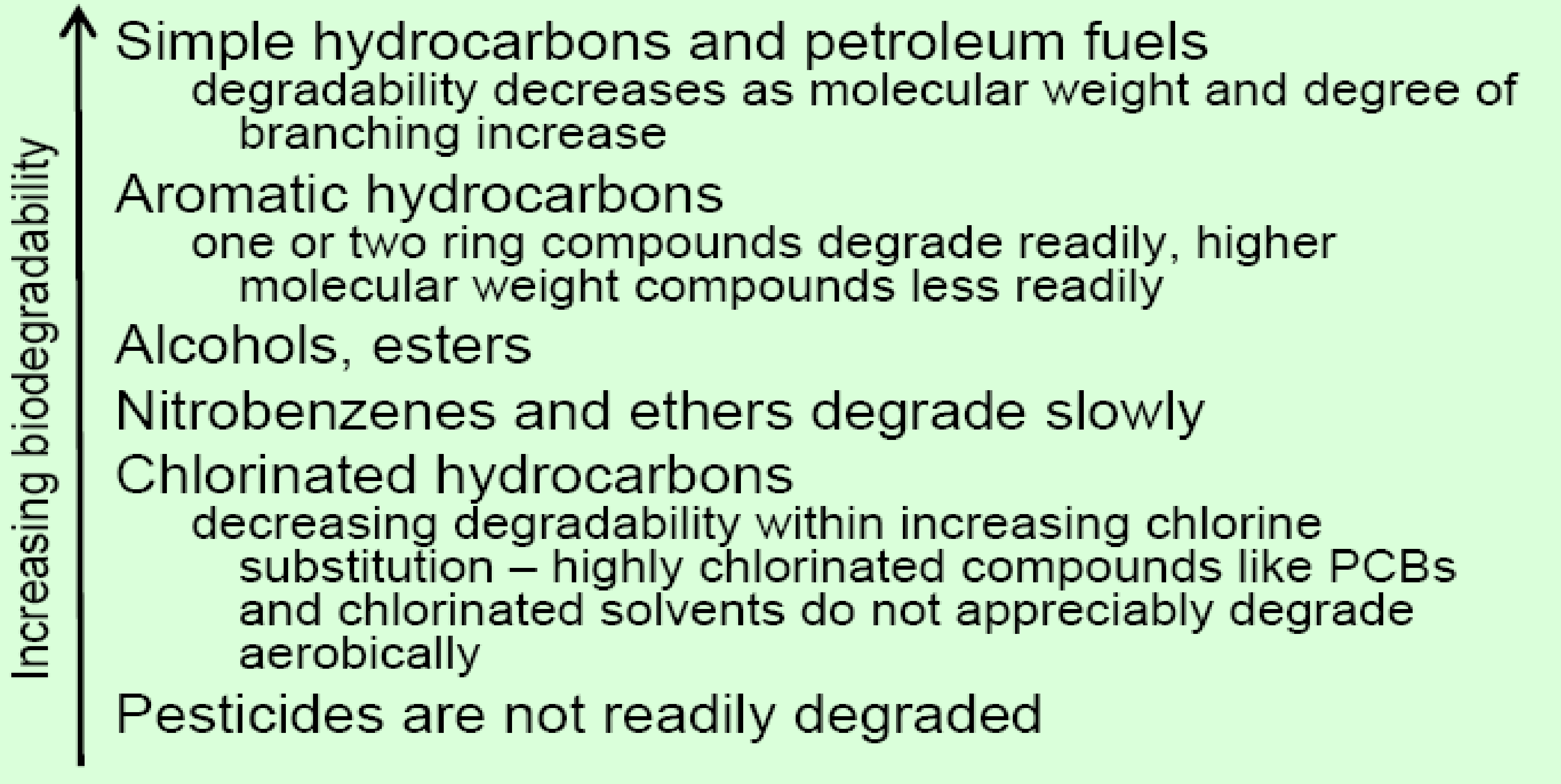
Transport and Reduction of Hg^{2+}

Geoff Gadd, Division of Environmental and Applied Biology, Biological Sciences Institute, School of Life Sciences, University of Dundee

Bioremediation

Applications, p. 33, 792

Relative biodegradability


Increasing biodegradability

Simple hydrocarbons and petroleum fuels

- degradability decreases as molecular weight and degree of branching increase

Aromatic hydrocarbons

- one or two ring compounds degrade readily, higher molecular weight compounds less readily

Alcohols, esters

Nitrobenzenes and ethers degrade slowly

Chlorinated hydrocarbons

- decreasing degradability within increasing chlorine substitution – highly chlorinated compounds like PCBs and chlorinated solvents do not appreciably degrade aerobically

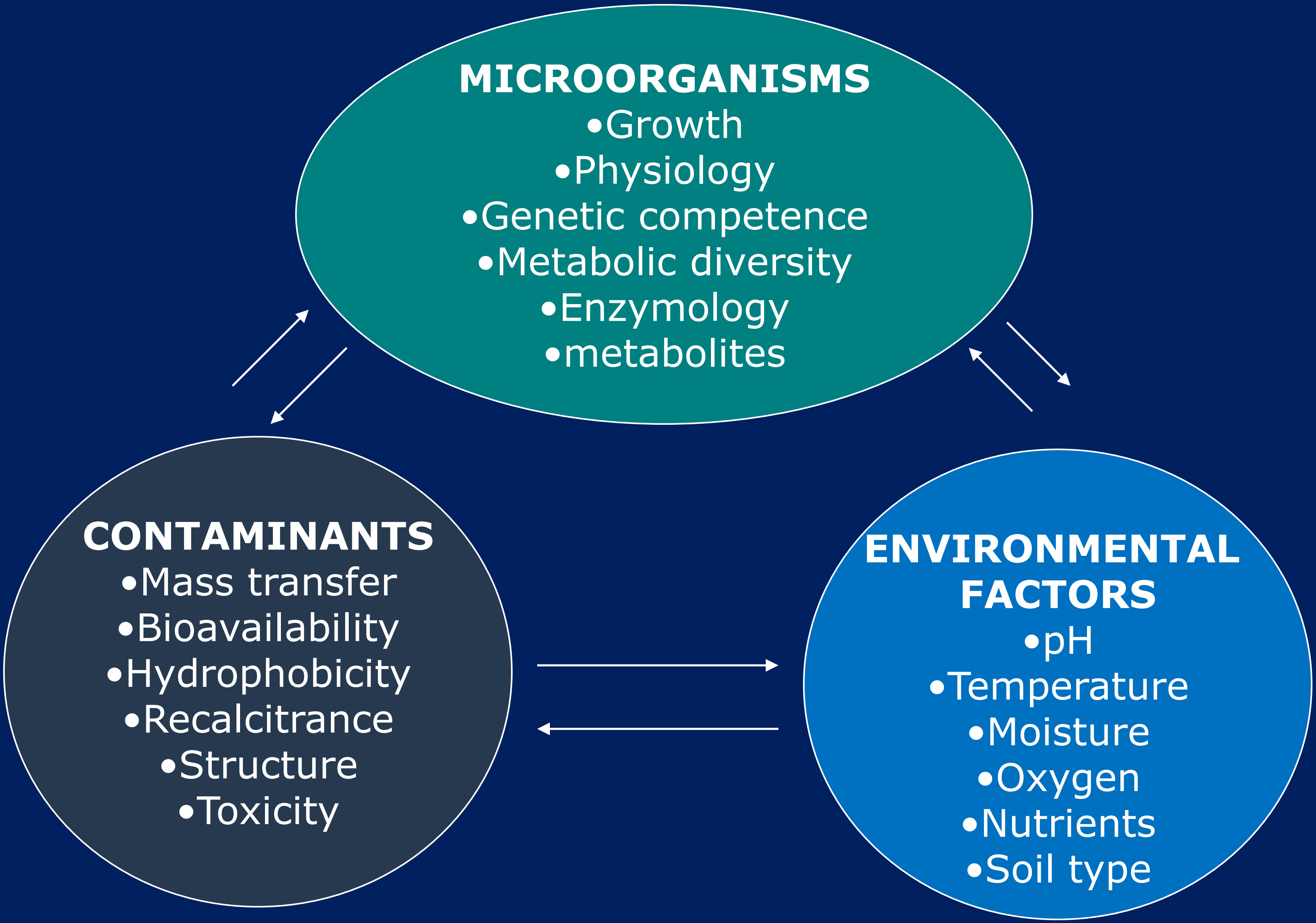
Pesticides are not readily degraded

BIODEGRADATION

- The breakdown of organic compounds by micro-organisms

- How might microorganisms attack hazardous organic wastes?
  - Mineralize compound directly, compound converted to harmless inorganic molecules such as carbon dioxide and salts
  - Of prime importance are microorganisms capable of producing enzymes that will degrade the hazardous chemical (target compound) as enzymes degrade compounds through exploitation of the organism’s energy need.
  - Converting compound to some other compound, which may also be toxic and recalcitrant to further degradation

BIODEGRADATION SYSTEM IN BIOREMEDIATION



MICROORGANISMS

- Growth
- Physiology
- Genetic competence
- Metabolic diversity
- Enzymology
- metabolites

CONTAMINANTS

- Mass transfer
- Bioavailability
- Hydrophobicity
- Recalcitrance
- Structure
- Toxicity

ENVIRONMENTAL FACTORS

- pH
- Temperature
- Moisture
- Oxygen
- Nutrients
- Soil type

What Types of Compounds Can Be Treated Biologically?

- Petroleum Hydrocarbons
  - Gasoline
  - Diesel Fuel
  - Gasoline Additives such as MTBE
- Polyaromatic Hydrocarbons
  - Creosote
- Chlorinated Hydrocarbons
  - Chlorinated Aliphatics: trichlorethylene
  - Chlorinated Aromatics : PCB’s, Pentachlorophenol
- Explosives
  - RDX, TNT
- Inorganics via Reduction to a Lower Valence Causing Precipitation
  - Uranium, Technicium
  - Sulfur and Sulfuric Acid
  - Ammonia or Nitrate/Nitrite

What Biological Technologies Are Available?

- In situ Bioremediation (ISB) or Enhanced Bioremediation
- Natural Bioremediation
- Biopiles
- Bioreactors
- Bioventing/ Biosparging
- Engineered Treatment Cells

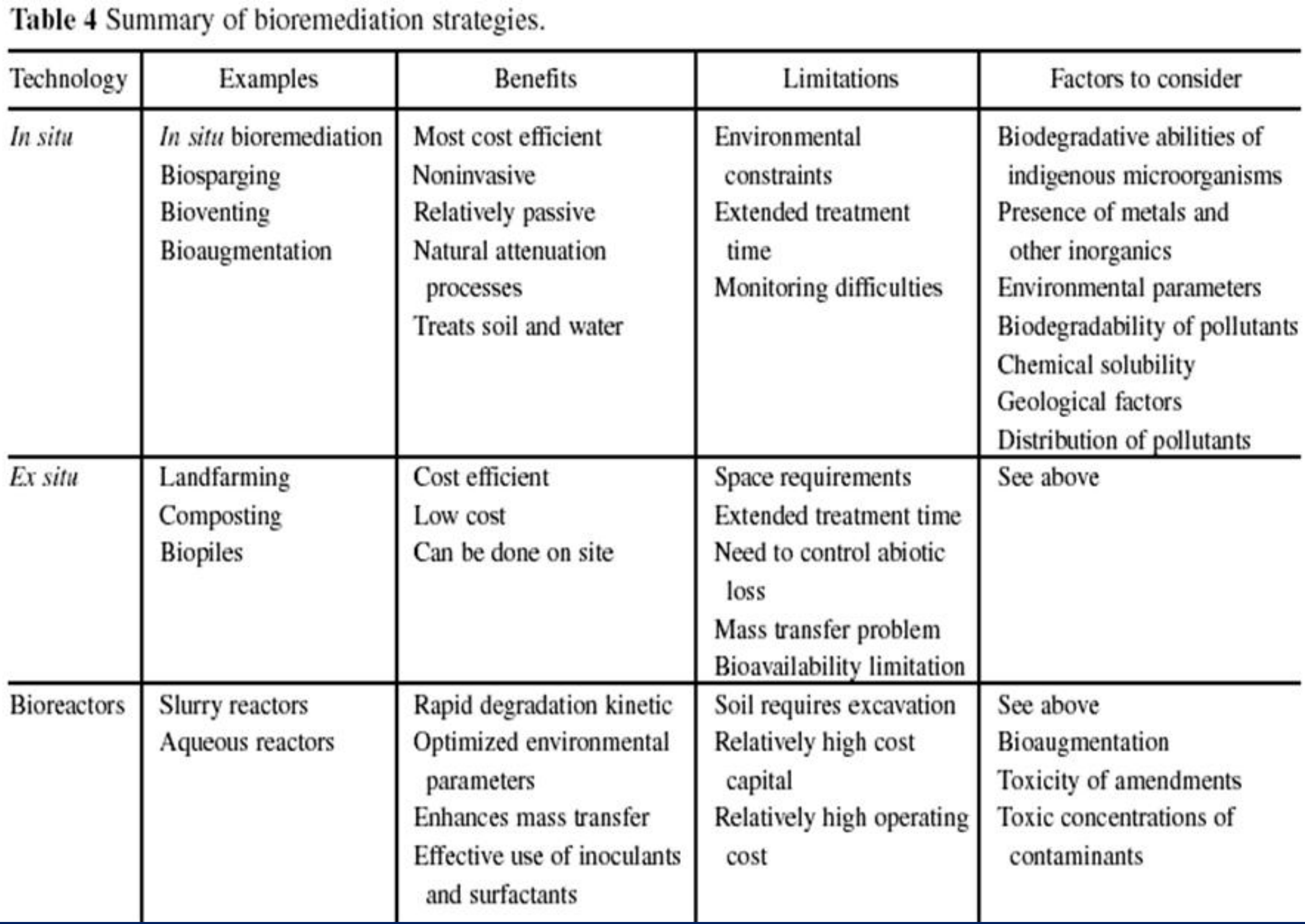
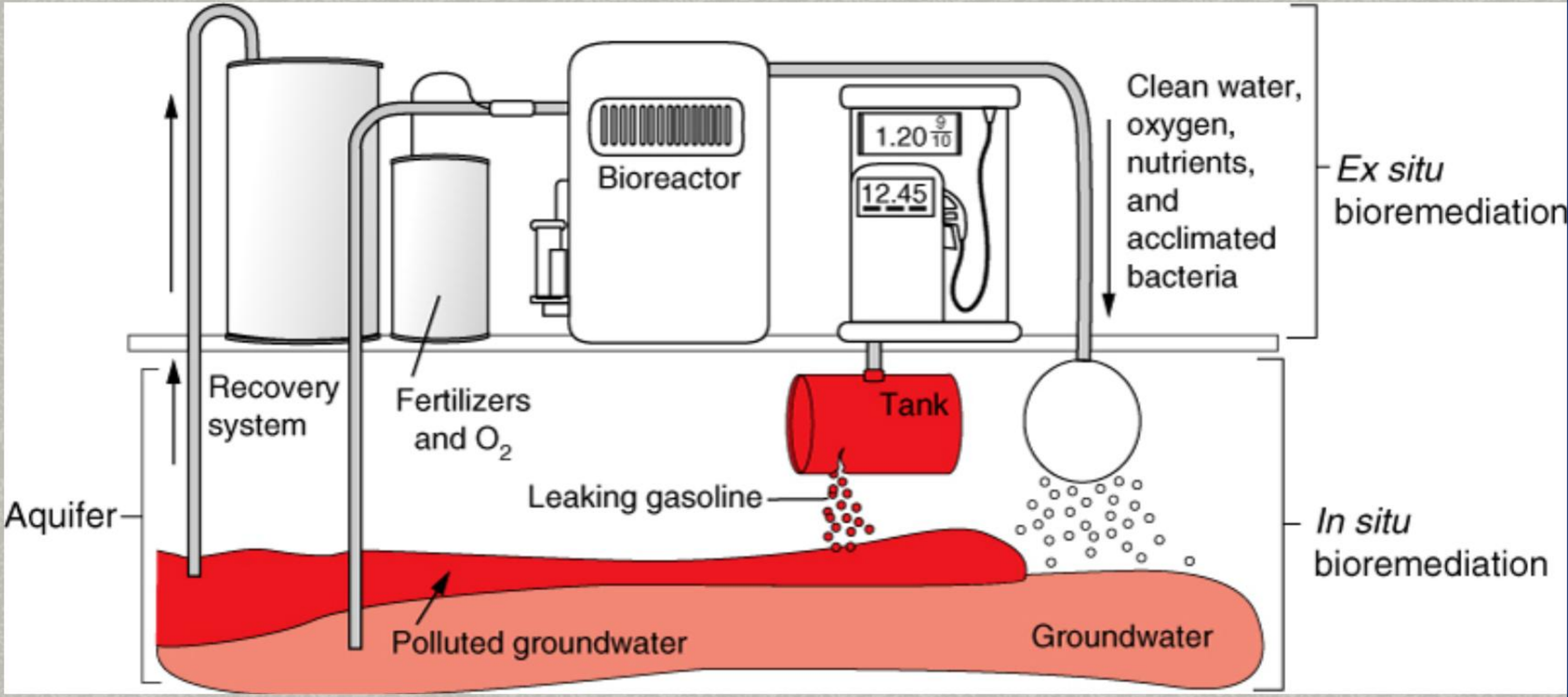


Table 4 Summary of bioremediation strategies.

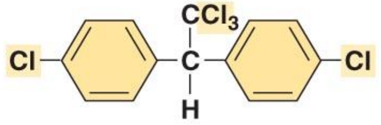
Technology	Examples	Benefits	Limitations	Factors to consider
In situ	*In situ* bioremediation Biosparging Bioventing Bioaugmentation	Most cost efficient Noninvasive Relatively passive Natural attenuation processes Treats soil and water	Environmental constraints Extended treatment time Monitoring difficulties	Biodegradative abilities of indigenous microorganisms Presence of metals and other inorganics Environmental parameters Biodegradability of pollutants Chemical solubility Geological factors Distribution of pollutants
Ex situ	Landfarming Composting Biopiles	Cost efficient Low cost Can be done on site	Space requirements Extended treatment time Need to control abiotic loss Mass transfer problem Bioavailability limitation	See above
Bioreactors	Slurry reactors Aqueous reactors	Rapid degradation kinetic Optimized environmental parameters Enhances mass transfer Effective use of inoculants and surfactants	Soil requires excavation Relatively high cost capital Relatively high operating cost	See above Bioaugmentation Toxicity of amendments Toxic concentrations of contaminants

Groundwater clean-up

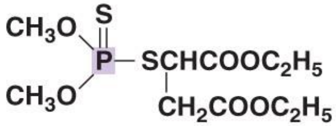
- In place or removed used



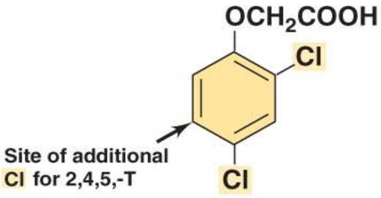
Examples of Xenobiotic Compounds



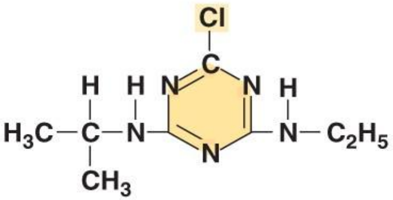
DDT; dichlorodiphenyltrichloroethane (an organochlorine)



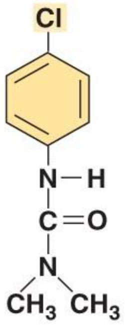
Malathion; mercaptosuccinic acid diethyl ester (an organophosphate)



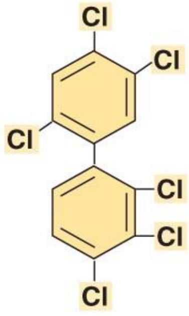
2,4-D; 2,4-dichlorophenoxy acetic acid



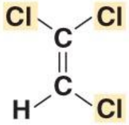
Atrazine, 2-chloro-4-ethylamino -6-isopropylaminotriazine



Monuron; 3-(4-chlorophenyl)-1 1-dimethylurea (a substituted urea)



Chlorinated biphenyl (PCB); shown is 2, 3, 4, 2′, 4′, 5′-hexachlorobiphenyl



Trichloroethylene

Figure 24.23

Pathway of Aerobic Herbicide 2,4,5-T Biodegradation

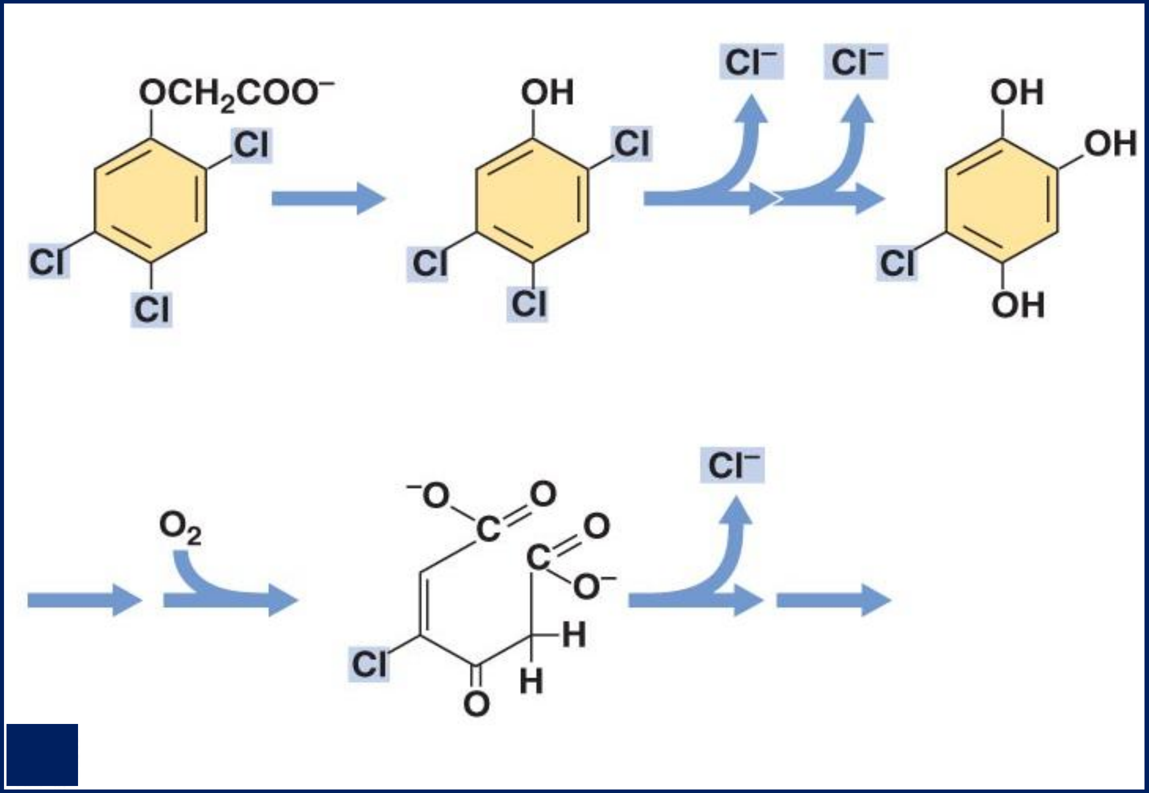
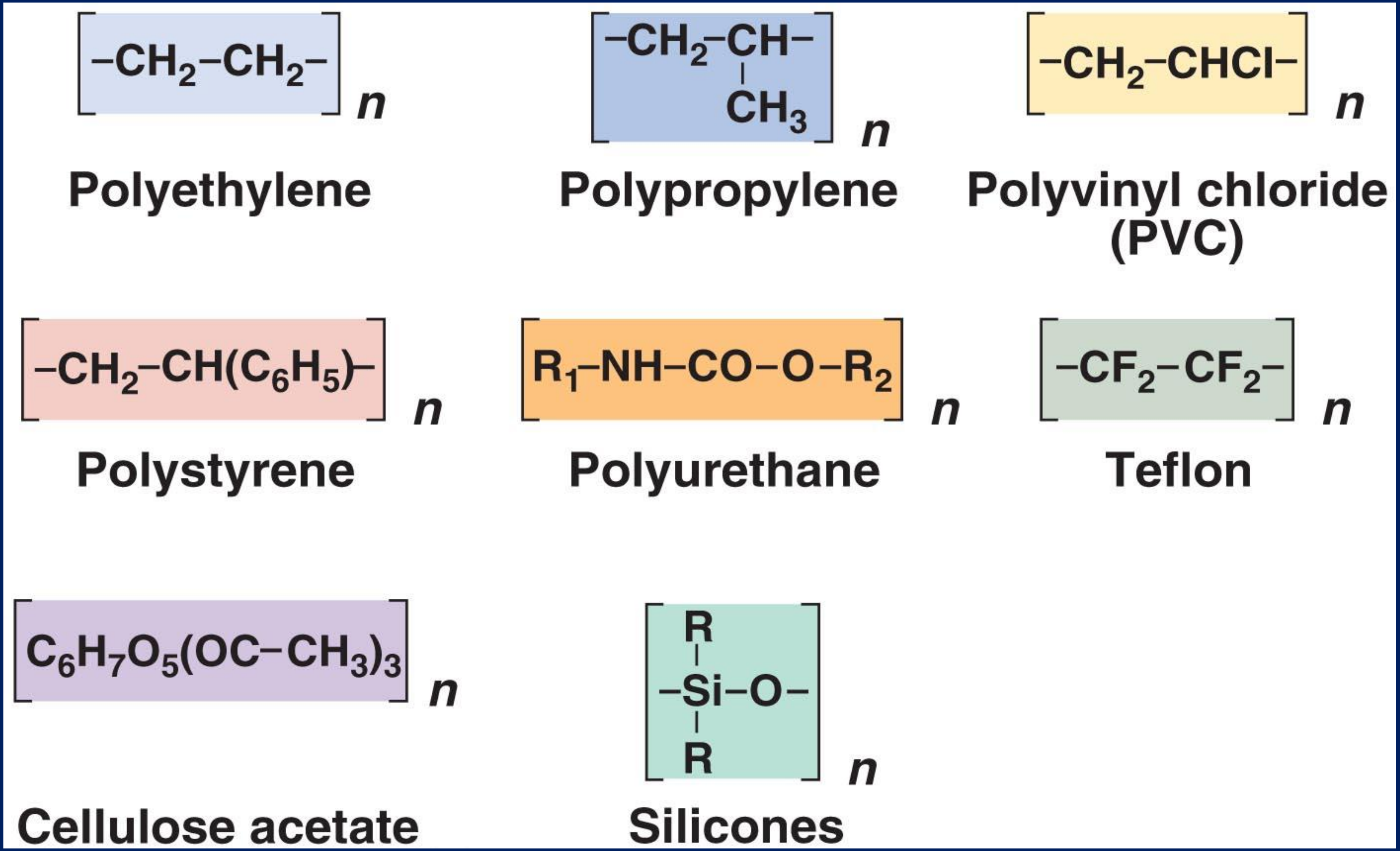


Figure 24.24b

Chemistry of Synthetic Polymers



$[-CH_2-CH_2-]_n$

Polyethylene

$$\left[\begin{array}{l}-CH_2-CH- \\ \qquad\quad\;\; | \\ \qquad\quad\; CH_3\end{array}\right]_n$$

Polypropylene

$[-CH_2-CHCl-]_n$

Polyvinyl chloride (PVC)

$[-CH_2-CH(C_6H_5)-]_n$

Polystyrene

$[R_1-NH-CO-O-R_2]_n$

Polyurethane

$[-CF_2-CF_2-]_n$

Teflon

$[C_6H_7O_5(OC-CH_3)_3]_n$

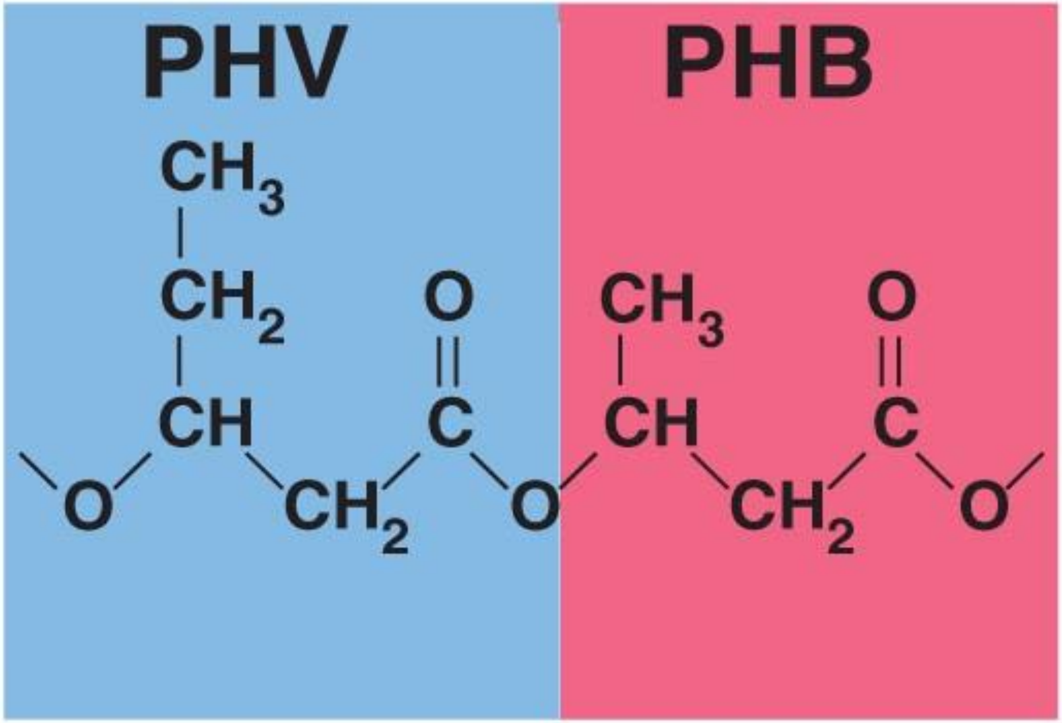
Cellulose acetate

$$\left[\begin{array}{c}R \\ | \\ -Si-O- \\ | \\ R\end{array}\right]_n$$

Silicones

Figure 24.25

Bacterial Plastics



Poly-β

Figure 24.26a